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Founders of Seismology.—II. Robert Mallet.

By Charles Davison, Sc.D.

WHILE Michell's interest in geology lasted until at least 1788, he made no further known contribution to the study of earthquakes. He must have been aware of the disastrous Calabrian earthquakes of 1783, but he would no doubt regard them as timely illustrations of his theory. The eighty years which followed 1760 were, indeed, somewhat barren as regards the progress of seismology. Among the more important contributions during this period were Dolomieu's report on the Calabrian earthquakes of 1783, Darwin's memoir on the connexion of certain volcanic phenomena in South America (1838), and the well-known chapters in Lyell's *Principles of Geology* (1830).

About the year 1840 a new period began, a period of rapid progress, during the first forty years of which the outstanding figures were those of Alexis Perrey in France and Robert Mallet in England. A brief reference should, however, be made to the work of David Milne (afterwards Milne Home) on the earthquakes of Great Britain, and especially on the remarkable series of Comrie earthquakes, which began in October, 1839, and lasted for the next six years.[1]

The work of Alexis Perrey was almost concurrent with that of Mallet, Perrey's lasting from 1841 to 1875, and Mallet's from 1845 to 1878. Perrey was professor of mathematics at Dijon. Except for his seismic bibliography (1855–65) and his papers on the relation between the frequency of earthquakes and the age of the moon (1853, 1861, and 1875), he devoted himself to the heavy and uninspiring task of cataloguing earthquakes. His catalogues were of two kinds, chronological and geographical. The former consist of lists of earthquakes in all parts of the world for each year from 1843 to 1871. The regional catalogues, seventeen in number, cover the whole of Europe, with the exception of Russia, Scandinavia, Denmark, and Germany outside the basin of the

[1] *Edin. New Phil. Journ.*, vol. xxxi, 1841, pp. 92–122, 259–309; vol. xxxii, 1842, pp. 106–27, 362–78; vol. xxxiii, 1842, pp. 372–88; vol. xxxiv, 1843, pp. 85–107; vol. xxxv, 1843, pp. 137–60; vol. xxxvi, 1844, pp. 72–86, 362–77.

Rhine. Of the other continents, only special regions are considered—in Asia, the Philippine Islands, Japan, and the Kurile Islands and Kamschatka; in Africa, Algeria and the north of the continent; in America, the Antilles, Chile, Peru, and the Aleutian Islands, Alaska, etc. Regarding the interior of the earth as fluid, it was only natural that Perrey should investigate a lunar periodicity[1] in the occurrence of earthquakes, but his three laws of greater frequency at syzygies than at quadratures, at perigee than at apogee, and, for any place, when the moon crosses the meridian, can hardly be regarded as possessing a firm foundation. His chief claim to our gratitude rests on his extensive catalogues. Our knowledge of the history of nearly every seismic region of the globe depends at one point or another on the untiring labours of Alexis Perrey.

In other respects the ground was unoccupied. Our knowledge of individual earthquakes was gradually increasing, the facts of earthquake phenomena were becoming known, but, as yet, there was no science of seismology. The next step was made, not by a trained student, but by a busy practical engineer; and when we think of the work which Mallet accomplished for seismology we should also remember that it was done, for the most part alone and unaided, in the midst of great engineering enterprises.

Robert Mallet was born at Dublin on June 3, 1810, his father, John Mallet, being the proprietor of a factory in which sanitary fittings and small fire-engines were made. At the age of 16 Mallet entered Trinity College, Dublin, taking the degree of B.A. after a four years' course. In the following year (1831) he married and was taken into partnership in his father's factory. This he soon converted into engineering works with a considerable foundry, and before many years had passed all the engineering work of any consequence in Ireland was carried out by the firm. Mallet's first great feat was to raise the roof of St. George's Church, Dublin, a mass 133 tons in weight, and covering a large area. This was followed by the building of several bridges over the Shannon, and the invention and construction of hydraulic rams and of ventilating and heating apparatus for public buildings. His buckled plates, which he began to make in 1840, form one of the best floors ever designed, combining the maximum of strength with the minimum of depth and weight. They are to be found on the Westminster and other London bridges. In 1845–6 he was erecting a railway station while he was working at his first important paper on the dynamics of earthquakes. In 1849–55 he built various station roofs, and the Fastnet Rock lighthouse, and was designing heavy guns and large mortars, the latter capable of throwing 36 inch shells. At the same time he

[1] It is interesting to notice that the possibility of a lunar periodicity occurred to Darwin in 1840. Writing to D. Milne, he remarks, "On the hypothesis of the crust of the earth resting on fluid matter, would the influence of the moon (as indexed by the tides) affect the periods of the shocks, when the force which causes them is just balanced by the resistance of the solid crust?" (*More Letters of Charles Darwin*, vol. ii, 1903, p. 115).

was writing his British Association reports on the facts of earthquake phenomena, determining the velocity of earth-waves in sand and solid rock, and compiling his catalogue of recorded earthquakes. In 1859 he wrote a valuable paper on the coefficients of elasticity and rupture in wrought iron, and at about the same time worked out the results of his investigation of the Neapolitan earthquake of 1857, and made further experiments on the velocity of earth-waves at Holyhead.

In 1861, engineering work becoming scarce in Ireland, Mallet moved to London, where he set up as a consulting engineer and edited the *Practical Mechanic's Journal*. After an active and healthy life his eyes began to fail during the winter of 1871–2, and he was practically, though not quite, blind during the last seven years of his life. He died on November 5, 1881.

"In scientific thought Robert Mallet was remarkable for the originality of his ideas, and for the broad grasp he took of every subject that engaged his attention; in private and social life he was beloved for the kindness, geniality and humour of his disposition, for his readiness in conversation and uniform good temper."[1]

Until he was about 35 years old, Mallet, like Michell, had apparently given no thought to earthquakes. His attention was drawn to them, not by a great disaster, but almost by accident. He had noticed in Lyell's *Principles* the well-known diagram of a pair of pillars, the upper parts of which had been twisted without being overthrown, by one of the Calabrian earthquakes. He saw at once the flaw in the usual statement that, under each pillar, there must have existed an independent vorticose movement. His practical training suggested a simple mechanical explanation. If the centre of adherence of the base of the twisted portion were to lie outside the vertical plane containing its centre of gravity and the direction of the motion, the result might be the observed rotation.[2] The problem is one of minor importance. Its interest lies chiefly in the fact that its solution led Mallet to the views on the nature of earthquake-motion which he described in his memoir on the dynamics of earthquakes.[3]

In this memoir, in addition to the discussion of the problem referred to, Mallet considers the nature of the earthquake-motion in the earth's crust, the nature and origin of seismic sea-waves and of earthquake sounds, the need and use of observations on the

[1] *Roy. Soc. Proc.*, vol. xxxiii, 1882, pp. xx. For the above biographical details I am chiefly indebted to notices in *Engineering*, vol. lii, 1881, pp. 352–3, 371–2, 389–90; and *Min. of Proc. of Inst. of Civ. Eng.*, vol. lxviii, 1882, pp. 297–304.

[2] Other, and perhaps more probable, explanations of the movement are given in *Trans. Seis. Soc. Japan*, vol. i, pt. ii, 1880, pp. 31–5, and GEOL. MAG., 1882, p. 264.

[3] "On the Dynamics of Earthquakes; being an attempt to reduce their observed phenomena to the known laws of wave motion in solids and fluids" (read February 9, 1846): *Trans. Irish Acad.*, vol. xxi, 1848, pp. 51–105.

velocity of earth-waves, and the advantage of founding earthquake observatories in various parts of the world. There is perhaps little that is really novel in the whole memoir, little, if anything, that the present-day student of seismology would have occasion to consult, and his account of Michell's work is strangely inaccurate and incomplete. Its chief merit is that it does form an attempt to explain the more important phenomena of earthquakes by the light of one guiding principle, and thus, as he says, to bring them within the range of exact science. As W. Hopkins wrote in the following year, he treated the subject " in a more determinate manner and in more detail than any preceding writer ".

The principle referred to is that an earthquake is " the transit of a wave of elastic compression in any direction, from vertically upwards to horizontally, in any azimuth, through the surface and crust of the earth, from any centre of impulse, or from more than one, and which may be attended with tidal and sound waves dependent upon the former, and upon circumstances of position as to sea and land ".[1] At the same time, he realized that the waves of vibration may " become complicated by movements of permanent elevation or depression in the land . . . the effects of which it may often be difficult or impossible subsequently to separate."

Mallet gives a very full description of the sea-waves which accompany earthquakes. Although he does not follow Michell in separating the visible waves from the waves of vibration on land, he distinguishes two kinds of sea-waves—the forced sea-wave, as he calls it, and the great sea-wave. His explanations of the origin of both are partially incorrect. The forced sea-wave, which accompanies the earth-waves and is " carried upon its back, as it were ", is merely the wave of compressional vibrations in water. If the great sea-wave, which sweeps in some time later, were initially raised by the earth-wave, there would be a great sea-wave with every strong submarine earthquake. He does, however, notice that the sea-wave may become " complicated by movements of permanent elevation or depression in the land ", and to this extent his explanation is no doubt correct.

Great stress is laid on the importance of determining the velocity of the earth-wave, not so much for the interest of the question in itself, as on account of its geological applications. Mallet was aware that the velocity in any rock must depend on the elastic constants of the rock. If we were to measure these constants for all the different rocks, the knowledge of the velocity in a given submarine earthquake, he suggested, would enable us to predict

[1] Many earlier writers had regarded earthquakes as due to the passage of waves of vibration, e.g. J. Michell in 1760, Thomas Young in 1807 (*Lectures on Natural Philosophy*, vol. i, p. 717), and D. Milne in 1841 (*Edin. New Phil. Journ.*, vol. xxxi, pp. 262, 275–7). In his report on the theories of elevation and earthquakes (*Rep. Brit. Assoc.*, 1847, pp. 33–92), W. Hopkins, treating the theory as obvious or well known, gives an account of wave-motion in solids and liquids that may still be read with advantage.

the nature of the underlying rock-formations—an anticipation which has not, I am afraid, so far been fulfilled.

In his early views on the origin of earthquakes Mallet was in advance of his time. He connects earthquakes with "local elevations of portions of the earth's crust, often attended with dislocation and fracture of the crust, and sometimes attended with the actual outpouring of liquid matter from beneath." He imagines an earthquake to be produced "either by the sudden flexure and constraint of the elastic materials forming a portion of the earth's crust, or by the sudden relief of this constraint by withdrawal of the force, or by their giving way, and becoming fractured". Where should we look for such sudden changes? Not in volcanic countries, he thinks, but rather in that broad sub-oceanic belt within which the deposits of the land are accumulated and from which they may afterwards be swept away by tidal currents. "Such a condition of the sea-bottom would seem to be the most likely state of things to give rise to frequent and sudden local elevations or even submarine eruptions of molten matter." And he notices that, while earthquakes are frequent in volcanic countries, they are never of the greatest violence. On the other hand, "the centre of disturbance of almost all the greater earthquakes appears to be beneath the sea, and at considerable distances from active volcanoes," while "the circumstances of the great sea wave seem to indicate that the centre of disturbance is seldom, if ever, *very* distant from the land".

I have given a somewhat full account of this important memoir, for whatever its imperfections may be it must, I think, be regarded as the chief foundation-stone of seismology as a science. Fortunately Mallet did not rest content with this, practically his first, contribution. He became afterwards widely known to the scientific public by his four reports to the British Association on the facts of earthquake-phenomena, their publication covering most of the years from 1850 to 1858. His crowning work on the Neapolitan earthquake of 1857 was published in 1862. With this report and with his memoir on the velocity of earth-waves at Holyhead, his career as a seismologist practically ended, for his study on volcanic energy lies outside our range, and his later papers, owing to his practical blindness, were of minor value. After his first memoir Mallet's work may thus be considered under the following headings: (i) experiments on the velocity of earth-waves; (ii) the preparation and discussion of the catalogue of recorded earthquakes; (iii) the development of methods of investigating earthquakes; and (iv) their application to the study of the Neapolitan earthquake.

Velocity of Earth-waves.—As already remarked, Mallet attached great importance to accurate determinations of the velocity of earth-waves. His first experiments were made in two widely differing materials—the wet sand of Killiney Bay, on the coast of Co. Dublin, and the granite of the neighbouring Dalkey Island. In Killiney Bay charges of 25 lb. of gunpowder were exploded in

the sand, and the passage of the waves at a distance of half a mile was detected by the tremors on the surface of a mercury bath. In Dalkey Island the ranges were of less than half this length (1021–1155 feet), the granite in one set being of a more fissured or shattered character than that in the other. The mean of eight measurements in sand, six in the fissured granite and three in the other, gave the following velocities, after all corrections were applied :—

Sand	825 feet per second.
Discontinuous granite . . .	1,206 ,, ,, ,,
More solid granite	1,665 ,, ,, ,,

The second series of measurements were made at Holyhead from 1856 to 1861, large masses of rock being dislodged from the Government quarries by the explosion of from one to five or more tons of gunpowder in mines. The ranges (six in number) varied from slightly less than a mile to about a mile and a quarter, crossing different lengths of quartz rock, slates, and schists. The velocities varied from 954 to 1,289 feet per second, the average of all six measurements being 1,089 feet per second.[1]

Catalogue of Recorded Earthquakes.—In the compilation of his earthquake catalogue, as well as in the experiments described above, Mallet was assisted by his eldest son, the late J. W. Mallet. The catalogue forms his third report on earthquake-phenomena, and occupies nearly six hundred pages in the reports of the British Association. The discussion of the catalogue and the description of the seismic map of the world are contained in the fourth report.[2] Though based on several earlier catalogues—especially those of Von Hoff, Cotte, Hoffman, Merian, and Perrey—Mallet regarded his catalogue as probably the first attempt to include all recorded earthquakes. The labour involved in its preparation must have been immense. From scattered sources—books of travel, British, French, and German newspapers and scientific journals—the number of entries obtained amounted to about one-half the total number. The details relating to each earthquake are given in tabular form under the six headings : time of occurrence, area chiefly affected, the direction, duration, and number of the shocks, great sea-waves, etc., meteorological and secondary phenomena, and the authorities for the records. The first entry is under the date 1606 B.C., and Mallet originally proposed that the catalogue should end with the year 1850. It was found, however, that the completeness of Perrey's annual catalogues rendered its extension beyond the year 1842 unnecessary, but the earthquakes of the eight omitted years are included in the discussion of the fourth report. The total number

[1] *Rep. Brit. Assoc.*, 1851, pp. 272–317 ; *Phil. Trans.*, 1861, pp. 655–79 ; 1862, pp. 663–76. The above velocities are given to the nearest foot per second. Mallet expresses them to three places of decimals. Such detail, however, is meaningless, for an error of one-hundredth of a second in the time of transit at Killiney Bay involves an error of more than 2 feet per second in the velocity.

[2] *Rep. Brit. Assoc.*, 1852, pp. 1–176 ; 1853, pp. 118–212 ; 1854, pp. 1–326 ; 1858, pp. 1–136.

of earthquakes recorded is stated by Mallet to be 6831, of which 216 were "great" earthquakes, or strong enough to reduce whole towns to ruins. Judging from the last 150 years, during which the record of such disasters may be supposed complete, Mallet estimates that a great earthquake occurs on an average once every eight months. The rapid expansion in the number of entries, especially during the last three centuries, is no proof, in Mallet's opinion, of any actual increase in earthquake-frequency. He regards it as, in fact, "a record of the advance of human enterprise, travel, and observation," the evidence tending rather to the conclusion that "during all historic time the amount of seismic energy over the observed portions of our globe must have been nearly constant." At the same time, there is clear evidence of irregular and paroxysmal outbursts of energy in reference to shorter periods. The frequency curves for the last three centuries and a half (1500–1850) show, indeed, that while the least interval of repose may be a year or two, the average interval is from five to ten years; that the shorter intervals are usually connected with periods of diminished earthquake frequency; that the alternations of paroxysm and repose appear to follow no discernible law; except that two marked periods of extreme paroxysm occur in each century, the greater about the middle and the less not far from the end.

Still more important are Mallet's conclusions on the distribution of earthquakes in space. Previous seismic maps of the world, such as those in the physical atlases of Berghaus and Johnston, were based on imperfect catalogues. In neither, as he notices, is there any attempt made to depict by various tints the greater or less frequency and violence of earthquakes in different areas. Mallet's materials were much fuller, though still far from complete. The original map, on Mercator's projection, is 75 inches long and 48 inches wide (reduced in the report to about one-third linear dimensions). He divided earthquakes into three classes—great, mean, and minor. If their disturbed areas were unknown, he assumed that their radii were 540, 180, and 60 geographical miles, and their areas were coloured by three tints, the intensities of which were as the numbers 9, 3, and 1. Thus, the most deeply shaded areas on the map represent those in which earthquakes are most frequent and violent.

While its defects are obvious, Mallet's map remained for nearly half a century our best representation of the distribution of earthquakes over the globe. The more important results which he deduced from it are the following: as the distribution of earthquakes is paroxysmal in time, so also it is local in space; the normal type of distribution is in bands of variable and great width (from five to fifteen degrees); these bands very generally follow the lines of elevation which divide the great oceanic or terr-oceanic basins of the earth's surface; in so far as these are frequently the lines of mountain-chains, and these latter those of volcanic vents, so the seismic bands are found to follow them likewise; the regions of

least or no disturbance are the central areas of great oceanic or terr-oceanic basins and the greater islands existing in shallow seas. The modern and more accurate method of mapping by epicentres, rather than by disturbed areas, has led to greater detail in our knowledge, but the main laws of seismic distribution are those which Mallet has so clearly established.

Methods of Investigation.—Though they are not explicitly stated, there can be little doubt, I think, that the methods of investigation which Mallet afterwards developed, were partly present in his mind when he wrote his early papers. Even in the first edition (1849) of the *Admiralty Manual of Scientific Inquiry*, to which, on Darwin's recommendation, he was invited to contribute, there is no direct account of them in the section on the observation of earthquake phenomena. They are described for the first time, and very fully described, in his report on the Neapolitan earthquake, and it is some indication of the importance which he attached to them that the main title which he gave to these two large volumes is "The First Principles of Observational Seismology".

The fundamental object of Mallet's inquiry was to ascertain the surface-position and depth of the seismic focus. The methods which he proposed for this purpose are well known. By observations on the direction of fissures in large and uniform buildings, of the fall of columns, and of the projection of detached masses of masonry, he sought to determine the azimuth or horizontal direction of the shock, and such directions at two or more places would suffice to determine the position of the point vertically above the seismic focus, which we now know as the epicentre. Once this point is determined, a single observation of the angle of emergence, as given by the inclination of fractures in walls, would lead to the depth of, at any rate, one point within the focus.

Various writers before Mallet had suggested the use of observations on the direction of the shock. The earliest case known to me, which I have already quoted (p. 105), is that of J. Michell, in 1760. D. Milne used the method in 1841 to determine the epicentre of the Comrie earthquakes, which were at that time frequent, the directions at different places being obtained chiefly from the records of inverted pendulums. He also made the valuable suggestion that "if instruments could be invented which at different places would indicate, not merely the relative intensity of the shocks, but the direction in which they acted on bodies, means would be obtained of determining the point in the earth's interior from which the shocks originated"[1]—a method which, forty years later, occurred to J. Milne, and was used by him, and afterwards by Omori and Hirata, to determine the depth of the seismic foci of some Japanese earthquakes. Lastly, W. Hopkins, in giving (1847) the same method for locating the epicentre, adds the important remark that the direction observed should be that at

[1] *Rep. Brit. Assoc.*, 1841, p. 48; 1842, pp. 96–7; 1843, p. 121; *Edin. New Phil. Journ.*, vol. xxxi, 1841, pp. 276–7.

the first instant of the motion, for, afterwards, the later vibrations of the condensational wave and the earlier vibrations of the distortional wave may coalesce—a precaution which lies at the root of Galitzin's method.[1] It is one thing, however, to suggest a method, and a very different matter to apply it; and few, I think, will be found to deny that, if any name is to be associated with these methods, it should be that of Robert Mallet.

Study of the Neapolitan Earthquake of 1857.—Owing to his long residence in Ireland—a typical aseismic country—Mallet had no direct acquaintance with earthquakes until 1852. On November 9 of that year he was awakened by a strong shock, one that is perhaps unique among British earthquakes in having affected all four portions of the United Kingdom. It failed, however, to give him the materials that he required, and five years more had to pass before they were provided by the Neapolitan earthquake of December 16, 1857. Leaving Naples on February 10, he spent several weeks visiting the ruined towns and villages of the meizoseismal area, heedless of the many discomforts of a camp life during the wet and cold of winter, convinced that in fractured walls and overthrown pillars he had "the most precious data for determining the velocities and directions of the shocks that produced them", inspired by the thought that for the first time the depth of the seismic focus was being "measured in miles and yards with the certainty that belongs to an ordinary geodetic operation". Sixty years have passed since then; the certainty of 1858 may have given way to doubt; yet, as one reads the account of his work at Polla and Vietri di Potenza, when he realized that at last he had found the point vertically above the origin of the shock and could state, as a first approximation, that the depth of the focus was 5·64 geographical miles, one cannot but sympathize with his confidence that he was showing the way to a true intelligence of "the viewless and unmeasured miles of matter beneath our feet".

Mallet's report on the Neapolitan earthquake is the first of a long series of monographs on shocks of special strength or interest, and for forty years, until the Assam earthquakes of 1897, it remained without a rival. His map of the earthquake marks an epoch in seismology. For the first time isoseismal lines were drawn on such a map. There are four of these. The first surrounds the meizoseismal area, within which the towns were for the most part prostrated; the second includes places in which large parts were thrown down and persons were killed; the third those in which slight damage to buildings occurred without any loss of life; while the fourth bounds the area within which the shock was perceived by the unaided senses.

On this map Mallet also depicted the lines of wave-path at different places, taking the most probable mean direction when more than one was measured. The majority of the observations he found to

[1] *Rep. Brit. Assoc.*, 1847, pp. 82–3.

pass within a circle, $2\frac{1}{2}$ geographical miles in radius, with its centre close to the village of Caggiano. Of twenty-six separate wave-paths, twenty-three start from the vertical line through this centre at depths of less than $7\frac{1}{2}$ geographical miles. The mean depth of the focus he estimated at $5\frac{3}{4}$ geographical miles, and the probable vertical dimension of the focal cavity at about 3 geographical miles. Some of the azimuths, however, pass outside the Caggiano circle. From their various points of intersection Mallet concluded that the focal cavity was a curved fissure 9 geographical miles in horizontal length. The mean velocity of the earth-waves he found to be 788 feet per second. The amplitude and maximum velocity of the vibrations naturally varied greatly. At Polla, which is close to the epicentre, he estimated the amplitude at $2\frac{1}{2}$ inches, and the maximum velocity at 13 feet per second.[1]

Conclusion.—To sum up Mallet's contributions to seismology is not an easy task. One of the most important is also the most intangible—his influence on the different points of view from which earthquakes were regarded, say in 1845 and after the lapse of twenty years. Fifteen years after his death and nearly forty years after the Neapolitan earthquake, I was struck by the fact that of more than two thousand observers of the Hereford earthquake of 1896, one in every five gave unasked the direction of the shock. In the large towns the proportion rose to one in every three.

"It is given to no man," said Mallet, "so to interpret nature that his enunciation of her secrets shall remain for ever unmodified by the labours of his successors." Mallet's work was unfortunately no exception to this rule. Some of it may now be obsolete, but much of it remains. Several of the terms in daily use—seismology, seismic focus, angle of emergence, isoseismal line and meizoseimsal area—are due to him. The position of the epicentre may still be determined by observations on the direction of the shock, especially by the mean of a large number of observations. As regards the depth of the focus, the results derived from such observations are much less certain. All that can be said is that they perhaps indicate the order of magnitude of the true depth. His experiments on the velocity of earth-waves are interesting, though their bearing on the actual problem is somewhat remote. But, by his perception of the nature of earthquake-motion, by the construction of isoseismal lines, by the compilation of his great catalogue, by his statement of some of the laws which govern the distribution of earthquakes in time and space, and, above all, by his investigation—the first rational investigation—of a great earthquake, Mallet has placed the science of seismology under a debt, which those who have followed in his steps would be the last to underestimate.

[1] A more detailed account of Mallet's investigation is given in my *Study of British Earthquakes* (Contemporary Science Series), pp. 7–44.

ORIGINAL ARTICLES.

Precambrian Para-Gneisses of Southern Eyre Peninsula, South Australia.

By C. E. Tilley, Emmanuel College, Cambridge.

(PLATE III.)

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1. Introduction.

In an earlier paper[1] a description of certain dolomites and calc-magnesian silicate rocks of the oldest group recognized in southern Eyre Peninsula—the Hutchison series—has been given.

Intimately associated and interbanded with these dolomites occur a group of garnet gneisses along the shores of Sleaford Bay. A portion of the section exposed in this place was figured in the paper referred to.

The present notes are devoted to a description of these garnetiferous gneisses exposed at Sleaford Bay, together with a short account of some similar gneisses developed in the Hutchison area to the north.

2. The Sleaford Bay Section.

To the section already given in the previous communication a second is now added (Fig. 1 of the present paper). This section represents a continuation of the rocks exposed in an easterly

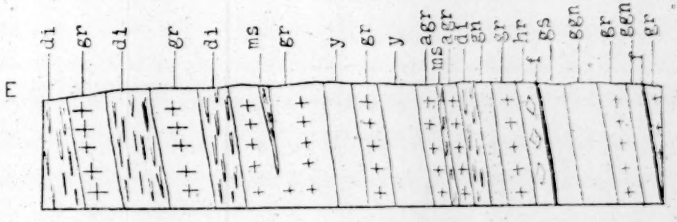

Fig. 1.—Section along the shore at Sleaford Bay.

←——————350 yards——————→

gr = granite, agr = aplitic gneiss, di = diopside rock, ms = mica schist, f = ironstone band, ggn = garnet graphite gneiss, hr = hornblende schist, gn = garnet gneiss, y = ? kaolinized schists with pegmatite veins.

direction. A number of beds forming the eastern extremity of the first section are again inserted in the accompanying diagram. The total length of section now revealed is approximately half a mile.

[1] C. E. Tilley, Geol. Mag., Vol. LVII, 1920, pp. 449–62, 492–500.

The members of the Hutchison series have been penetrated by sills of granite and pegmatite, and by veins of pegmatite and quartz, and composite rocks have in some cases thus arisen, consisting of bands of sediment alternating with igneous material.

3. The Garnet Gneisses.

(*a*) *General Description.*

The typical exposures of the garnet gneisses occur in the section immediately to the east of the massive beds of diopside-rock, which forms here a prominent headland on the coast. The gneisses are interbanded with the calc-magnesian silicate rocks (diopside-microcline-scapolite type) already referred to. The rapid change in composition of the rocks across the strike in this locality is remarkable. The garnet gneisses are conformably bedded with the calc-silicate sediments, striking north and dipping at a high angle—vertical to 80 degrees to the west. The most marked feature of the garnet gneisses as seen in the field is the parallel banded structure, which is essentially a structure arising from initial differences of composition in the original sediments. In certain cases banding has arisen due to the lit-par-lit intrusion of pegmatitic veinlets in the series, but a parallel structure arising in this way can be readily distinguished from the parallel banding due to original heterogeneity in the sediments. Additional garnet gneisses which enter for description here are developed to the east of the graphite gneisses (cf. section Fig. 1).

Here the banding is still evident, but garnet does not form such a prominent constituent. These are associated on the east with gneissic aplites, which in the field resemble these rocks in some particulars, but a study of thin sections reveals an essential distinction.

A bed of garnet gneiss with a well-developed parallel banding is present on the shore to the east of the sill of hornblende granite which borders the forsterite marble. It is separated from the granite sill by a thin bed of graphite schist.

(*b*) *Petrography of the Garnet Gneisses.*

(i) *Type a.*—The three types of garnet gneisses will be distinguished in this description by the prefixes α, β, γ, and this order is one of exposure from west to east. Their positions can be readily made out by reference to the sections. Type α is a banded rock of greyish colour and often with rusty weathered faces. In hand-specimens quartz, an unstriated felspar, garnet, and biotite can be detected, and also sparing flakes of graphite.

The parallel banding can be seen even in small fragments, as the width of the individual bands seldom exceeds $\frac{1}{8}$ in. The rose-pink garnets often show well-developed crystal outline (dodecahedra), and on weathered faces give rise to brown limonite. The rusty

weathering sometimes developed in these rocks is due to this degradation of garnet. The bands of quartz and felspar with garnet are separated by thin layers of biotite. The garnets reach $\frac{1}{4}$ in. in diameter, but average under $\frac{1}{8}$ in. Lenses of pegmatite with their long axes parallel to the surface of banding are occasionally present, and are readily picked out by their coarse texture.

In thin section the following minerals are seen to be present: Quartz, orthoclase, biotite, garnet, ilmenite (with leucoxene), plagioclase, graphite, and zircon.

Within the limits of the field of view of the 1 in. objective, the parallel banding of this rock is a marked feature. The mineralogical composition of the bands separates them into quartzose and felspathic layers.

Biotite occurs in elongated flakes, showing parallel orientation. The pleochroism is strong, and the scheme is—

Z = Y, red brown. X, pale straw yellow.

Faint pleochroic haloes surround small inclusions of zircon. The principal felspar is orthoclase, often intergrown with quartz. It is very characteristically a fibrous type, and is the dominant feature of the orthoclase felspar of all the garnet gneisses of this area.

The fibrous appearance is due to the presence of minute grains arranged parallel to the face (100), and the fibrous character disappears in many sections showing straight extinction. These features indicate the presence of an intergrowth which is probably perthitic, but the minuteness of the grains prevents the determination of other properties. In addition, in some of the orthoclase grains there are large spindle-shaped grains of a colourless mineral of higher relief and birefringence. They are oriented slightly obliquely to the perthitic type. In some cases these are certainly quartz, but in others represent an acid plagioclase. The quartz grains are characteristically elongated parallel to the banding surface, and may show rows of fluid pores at right angles to their elongation. In some sections the average elongation ratio reaches a value as high as 3 : 1.

Plagioclase is not abundant. It shows albite and pericline lamellation. The refractive index is about the same as quartz, but lower than the highest of quartz, and the sign of the birefringence is negative. The properties are those of an oligoclase-andesine. Myrmekitic intergrowths of plagioclase and quartz occur at the junction of plagioclase and orthoclase and often extend in a bay into the potash felspar.

Garnet is present in colourless porphyroblasts of rounded outline, with the typical quartz enclosures. It is usually quite isotropic, but an occasional grain shows anomalous birefringence, in one case with twinning lamellæ. The grains reach 3 mm. in size, but are usually smaller. The garnet is an almandine type, as might be expected in rocks of this class. This is confirmed by the characteristic

limonitic weathering product, and its fusion before the blowpipe to a black magnetic mass.

The colour of some of these garnets as seen in hand-specimens is often the characteristic purplish red of almandine.

Biotite and quartz are often wrapped around the periphery of these grains.

Graphite is invariably present in these rocks, and in some sections may rise to an important constituent. The orientation of the graphite flakes is like that of biotite, parallel to the banding, and in sections cut perpendicular to the foliation the flakes appear as elongated rods. In reflected light the flakes appear with a steel-grey lustre, like that of magnetite. The rod-like sections, however, have the characteristic frayed and serrated edges and a striated appearance on the ground surface, these features arising as a result of the softness of the mineral during grinding.

In these rocks these features, together with the rod-like sections, afford a ready means of distinction from magnetite. The graphite is usually associated with biotite, and is often enclosed by that mineral.

The order of abundance of the chief minerals in the rock is quartz, orthoclase, biotite, garnet, and plagioclase.

(ii) *Type β.*—The garnet gneisses described under this heading are interbanded with metamorphosed impure dolomites, now represented by rocks in which diopside is an important constituent. These gneisses are very similar to type *a* already described, but the banding and texture are here of a coarser nature. Rose-pink to purplish-red garnets are abundant often with good crystal outline, and average size of $\frac{1}{4}$ in. Dark mica is more abundant, and the general colour of fractured surfaces is dark grey. Steel-grey flakes of graphite are readily made out with a low-power lens. Weathered surfaces may show a prominent augen structure, the augen being of garnet, quartz, and felspar. These gneisses have in places been intruded by pegmatite veins, and composite types may thus be developed, in which part of the felspathic constituent is original and part introduced.

Under the microscope the minerals seen to be present are quartz, orthoclase, garnet, biotite, plagioclase, graphite, leucoxene, sphene, zircon, and a little muscovite and magnetite. The features of these rocks are so closely allied to those described for type *a*, that a detailed description is unnecessary. The potassic felspar is the typical fibrous perthitic variety. Plagioclase is more abundant than in type *a*, but is of the same composition—oligoclase andesine. A number of grains as calcic as andesine were, however, determined.

Almandine garnet occurs in grains of somewhat larger dimensions, and is invariably isotropic. The presence of the spessartite molecule is indicated by the presence of manganese. The remaining constituents of the rock swing round in a bulge when the almandine porphyroblasts are met. The elongated lenses of quartz parallel to

the foliation are a typical feature. Graphite is invariably present in the serrated rod-like sections, the orientation being that of the banding.

A finer grained rock of this type has the appearance in hand-specimens of a garnetiferous quartzite, but banding is still in evidence.

In thin section the rock is seen to be considerably more quartzose than the type already described. Plagioclase is a more important constituent, and the fibrous character of the orthoclase is less marked.

The garnets are characterized by a polygonal outline indicating a good crystal form. The banded character of this rock as seen under the microscope is strongly marked. The plagioclase shows curved albite lamellæ and wavy extinction due to strain, and often contains blebs of orthoclase as inclusions. The composition varies in different grains from oligoclase-andesine to a calcic andesine. In a further variety the minerals sillimanite and green spinel enter as accessory constituents.

The rock is very rich in quartz, and the fibrous perthitic character of the potash felspar, which is the next abundant constituent, is strongly developed.

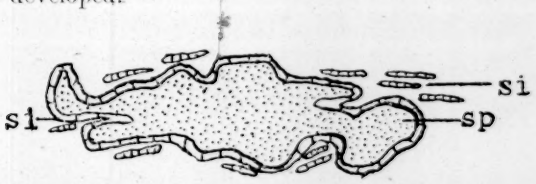

FIG. 2*a*.— × 50 diam. si = sillimanite, sp = spinel.

Biotite is plentifully distributed with its elongation parallel to the foliation. The pleochroism is—

Z = Y, dark brown. X, light yellow.

The sillimanite is developed in colourless elongated prisms with the prismatic axis parallel to the foliation.

These longitudinal sections show the characteristic cross parting parallel to the base. The elongation is positive. Usually the prisms are arranged in streaks and bands in the orthoclase, but may be associated with the garnet, which is present in irregular isotropic grains.

Very closely associated with the sillimanite occurs a deep-green spinel, which must be regarded as a member of the pleonaste-hercynite group, and probably nearer hercynite in composition, as the colour is a very deep green.

Some magnetite grains are associated with sillimanite in a similar fashion.

The sillimanite occurring in association with spinel forms a border

to the spinel grain, and the relationship is shown in the accompanying diagram (Fig. 2 (*a*)).

The sillimanite shell is not optically continuous, nor does the optical orientation bear a constant relation to the external shape of the spinel core.

(iii) *Type* γ.—This type of garnet gneiss outcrops to the east of the graphite gneisses shown in the section.

The rocks are fine-grained and microscopically have the appearance of quartzites. Garnet is present, but not in abundance. On the east they are associated with gneissic aplites, distinguishable by their texture and appearance in thin section. Under the microscope the rock is seen to consist of quartz orthoclase, biotite, garnet sillimanite, and a few grains of magnetite.

Quartz is very abundant in the slides, and has characteristically arranged in rows at right angles to the banding inclusions which appear to be of the nature of fluid pores.

These rows of dots are not only continuous through several contiguous grains of quartz, but also pass through adjacent grains of felspar. The phenomenon is clearly a result of shearing stress acting on the rock since its recrystallization, and the identical features of the Röhrsdorf granulites of Saxony are here recalled.

The felspar is the turbid perthitic orthoclase already described. Biotite occurs in elongated flakes parallel to the foliation, and the garnet, usually quite colourless, is often elongated parallel to the foliation, indicating a development under considerable stress.

Embedded in orthoclase, but with a streaky development, occur sillimanite needles, the orientation of the prismatic axes being parallel to the banding.

There is no evidence of granulation along the lines of sillimanite development.

A variety of this type contains in addition a green spinel, and the rock is richer in garnet. Quartz is again the most abundant constituent. The felspar is the fibrous orthoclase, and plagioclase is rarely observed.

The garnets are characterized by a habit, elongated in the direction of foliation. The elongation ratio of some of the apparently single grains may reach and exceed a value of 4 : 1. The significance of this will be dealt with hereafter, but it is clear that single grains have crystallized originally in a distinct elongated habit.

Hercynite, or a member of the hercynite-pleonaste group of spinels, is present and invariably associated with the garnet. It usually forms a deep-green isotropic core to a garnet grain, or may appear intergrown with this mineral. The depth of colour is not constant, and a gradation to an intense dark-green almost opaque type is observed (Fig. 2 (*b*)).

In one core of a garnet grain the spinel appears to have undergone alteration to a serpentinous product, in which are set residual grains of the spinel.

The garnet may sometimes contain minute rods of ilmenite (?), and scattered through the rock are opaque leucoxenic grains of the same mineral. Little prisms of sillimanite with their longer axes parallel to the banding are sparingly present in the orthoclase, or in some cases associated with the garnet.

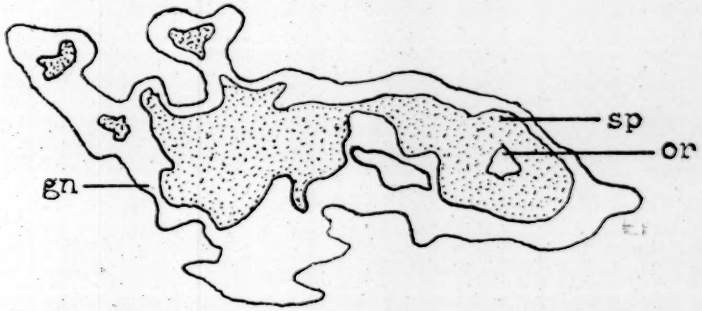

FIG. 2*b*.—× 50 diam. gn = garnet, sp = spinel, or = orthoclase.

(iv) *Type δ*.—Amongst the complex of metamorphosed sediments present in the Hutchison area, there are certain garnet gneisses, which in their field relations and microscopical character closely resemble the garnet gneisses of Sleaford Bay.

They are typically developed in the Waterfall Creek, and bound the dolomites of this area on the east.

These garnet gneisses are conformably bedded with the dolomites and strike north-east with a vertical inclination.

Those types which are allied to the Sleaford Bay occurrences will be here described.

They are dark-grey rocks with prominent garnets of a brownish-red colour, showing dodecahedral outline, and may be developed up to half an inch in size. Banding is a prominent feature.

Sillimanite may be detected in some specimens, with the aid of a lens, in long fibrous needles.

In places they have been invaded by quartz and pegmatite solutions, giving rise to lenses parallel to the foliation.

A rusty weathering appearance may be given to these rocks by the alteration of garnet to a limonitic product.

Under the microscope the typical sections are seen to consist of orthoclase, quartz, garnet, biotite, sillimanite, plagioclase, ilmenite. Orthoclase is the most abundant constituent. The fibrous character is not in evidence, but perthitic spots are present, characterized by higher refractive index and birefringence—essentially an albitic plagioclase.

The orthoclase shows considerably undulose extinction, and the periphery of the grains is marked by granulation giving the typical mortar structure. Quartz is nevef in large grains, but forms small individuals in bands separated by felspar.

Garnet may have a quite well-developed crystal outline. These grains reach 3 mm. in diameter. Owing to a prominent development of the dodecahedron the crystals are mainly rhombic and hexagonal in cross section, although elongate types are also occasionally developed. Through the prevalent occurrence of many inclusions of quartz, orthoclase, and biotite, the garnet shows the typical sieve structure. Green spinel may be intergrown with the garnet.

Along cracks biotite is developed (Pl. III, Fig. 1), and in some cases this is replaced by chlorite. This represents a degradation of the original garnet. In the angles of the grains biotite and quartz are often thickly developed, and this type of association is one of genetic significance. It is distinct from the development of biotite along cracks in the garnet, but is related to this change in that it represents a reaction which is a reversible one, the minerals involved being biotite and quartz on the one hand and garnet and orthoclase on the other (cf. equation in a later section).

The biotite is the characteristic red-brown variety, with intense pleochroism.

Sillimanite is an abundant constituent, and may form a zone of slender prisms at the periphery of garnet grains, a relationship in many cases of genetic significance. More characteristically it is present in streaks through the rock parallel to the banding and associated with orthoclase or biotite. The cross parting parallel to the base is a dominant feature.

Plagioclase is present in quite subordinate amount. It shows the albite lamellation, but the twinning lamellæ are usually bent owing to strain. The R.I. is greater than quartz. The majority of grains are positive, but a number show negative birefringence. Extinction angles from the albite lamellæ are quite unreliable owing to the shadowy extinction. The composition of the plagioclase is therefore at least as calcic as andesine.

This rock has suffered crushing, as indicated by the pronounced wavy extinction and granulation of the felspar.

In a varietal type containing a larger percentage of plagioclase the abundant porphyroblasts of garnet are intersected by a set of parallel cracks coincident with the foliation, and not normal thereto, as is usually the case. This structure implies the action of mechanical forces, the direction of the maximum pressure being at right angles to those in operation during the foliation and recrystallization of the rock (Pl. III, Fig. 2).

The fracturing of the garnets has evidently been induced in an epoch subsequent to the recrystallization, and may be connected with the pronounced crushing these rocks have undergone as revealed by the extensive granulation of the felspar.

Interbanded with these rocks occurs a garnet gneiss, showing coarse felspar porphyroblasts as well as garnet.

Under the microscope plagioclase is seen to be the dominant felspar, while orthoclase is the subordinate type.

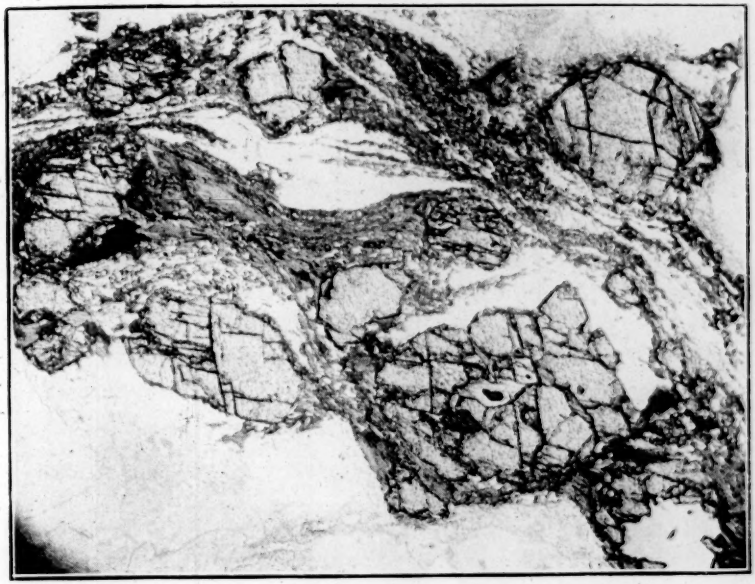

FIG. 2.

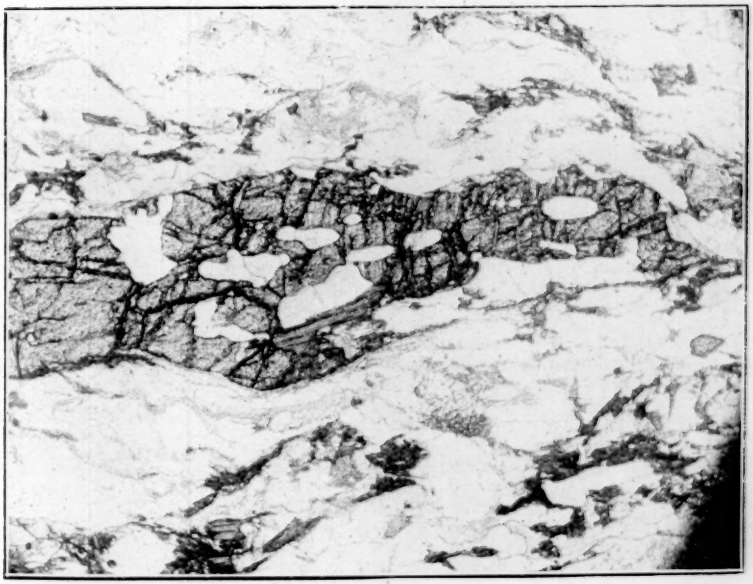

FIG. 1.

[To face p. 258.

This plagioclase has the composition of andesine, and around these larger grains flow the finer grained aggregates of quartz, biotite, and orthoclase. The undulose extinction and mortar structure are very marked features. This rock is of a remarkable composition for a sediment, but the field associations point to a sedimentary origin, as does also the abundance of fine-grained quartz.

The plagioclase probably represents recrystallized detrital plagioclase, the original rock being of the nature of an arkose. The garnet represents the by-product of the biotite-quartz interaction in the production of the orthoclase felspar.

(*To be continued.*)

An Outline of Chinese Geology.[1]

By J. S. Lee, M.Sc., Birmingham.

BEFORE we properly discuss the geology of China a few words on the geological work in that country will not be superfluous. Let us first of all ask the Chinese themselves if they, in the course of their intellectual evolution for thousands of years, have contributed anything valuable to our science. The inquiry into this point by the writer has so far been met by a negative answer. True, in ancient Chinese literature one often finds fragmentary suggestions and allegorical statements related to geology. As a typical example we may take the well-known expression "blue seas change into mulberry fields". This sentence is much quoted by popular writers either for depicting the ephemeral state of worldly affairs or for illustrating the slow, mighty change that persistently takes place on the earth. It is in the latter sense that it demands our attention. Again, there are a number of volumes both extremely ancient and comparatively modern treating of the drainage systems of China, and in some cases with rough indication of changes of the sea level. The descriptions of minerals like those in the "Bên-tsao-gang-mong" are certainly a record of incipient development of mineralogical study originated in China and by the Chinese; but as to the purpose, it was anything but geologic.

In recent years the devoted attitude of the Chinese literati to their metaphysical speculation and literatural indulgence has reluctantly but necessarily undergone a fundamental change under the pressing and penetrative influence of modern organized intellectual movements. Among the sciences thus introduced into China geology occupies its rightful place. Institutions for geological study have been established. A Geological Survey with Mr. V. K. Ting as the Director has already commenced its work. Although the *Record*

[1] This paper is an abstract of a Thesis which Mr. Lee submitted for the M.Sc. degree of the University of Birmingham in 1918, dealing with the Geology of China. The author is now Lecturer on Palæontology in the University of Peking, and attached to the Geological Survey of China. He has asked me to see the present paper through the press.—W. S. Boulton.

of the Work of the Geological Institute is so far the only document of its kind published in Chinese, we have little doubt that there will be a voluminous flow of Chinese geological literature in the near future.

Our present knowledge, then, is largely derived from the scientific writings of the western world. R. Pumpelly, in the years 1862–5, was the first to make a serious attempt to unravel the geological structure and history of Northern China. Three years later F. Richthofen began his life-work. As predecessors or early contemporaries of Richthofen perhaps we should mention A. David, who travelled across the Tsing-ling Range, in Mongolia, Kiang-si, and other provinces; T. W. Kingsmill, who visited many parts of the Yang-tze Valley; A. S. Bickmore, who journeyed from Canton to Hankow. Their labours, however, unlike the case of Richthofen, only resulted in the contribution of a few papers and comparatively brief reports.[1]

In the years 1877–80 L. Loczy [2] attached himself to the Expedition of Szechényi, and worked under difficult conditions in the lower Yang-tze Valley, parts of the Tsing-ling Range, the north part of the Nan-shan Ranges, the mountainous region of western Su-chuan and western Yun-nan. Several years later V. A. Obrutchov,[3] a Russian geologist, crossed and re-crossed the Nan-shan Ranges, and penetrated as far south as the northern border of the Great Red Basin of Su-chuan. Observations were also made by the same author in Inner Mongolia. K. Futterer [4] devoted himself for a time to the study of the geology of Central Asia and China. In journeying from the north-western border of the country to the Yang-tze Valley, Futterer gathered much material that deserves further analysis.

[1] A. David, *Journ. d'un voyage en Mongolie et d'un voyage en Chine dans le Kiang-si*; *Journ. de mon troisième voyage d'exploration dans l'Empire chinois*. T. W. Kingsmill, "Geology of the East Coast of China": *Journ. Geol. Soc. Dublin*; "A Sketch of the Geology of a portion of Quang-tung Province": *Journ. Brit. Roy. Asiat. Soc. N. China Br.*, N.S. II, 1865, pp. 1–38; "Notes of the Geology of China": *Quart. Journ. Geol. Soc.*, vol. xxv, 1869. A. S. Bickmore, "Sketch of a Journey from Canton to Hankow, etc.": *Journ. Brit. Roy. Asiat. Soc. N. China Br.*, N.S. iv, pp. 1–20, 1867; "Remarks on the recent Geol. Changes in China and Japan": *Amer. Journ. Sci. and Arts*, ser. ii, pp. 209–17, 1868.

[2] L. Loczy, *Die Beschreibung d. geol. Beob. u. d. Result. d. Reise d. Grafen Bela Szechényi in Ostasien*, 1877–80.

[3] V. A. Obrutchov, *Central Asia, Northern China, and the Nan-shan* (in Russian); "Geol. Sketch along the route from Fun-chou-fu to Lan-joi": *Izv. I.R.G. Soc.*, vol. xxix, 1893, pp. 391–407; "Kurz geol. Ski. d. Karawanstrasse v. Kjachta b. Kalgan": *Izv. I.R.G. Soc.*, vol. xxix, pp. 347–390; "Sketch of Central Nan-shan Range": *Izv. I.R.G. Soc.*, vol. xxx, 1894, pp. 709–34; "Orogra. u. geol. Umriss d. Central Mongolei, Ordos, Ost Kan-su u. N. Shen-si": *Izv. I.R.G. Soc.*, vol. xxx, 1894, pp. 231–53.

[4] K. Futterer, "Durch Asien: Die allgemeinen geol. Ergeb. d. neu. Forsch. in Zentral-Asien u. China": *Peter. Mitt.*, 1897, Ergan. Nr. 119, pp. 1–60; "Ueber Gestalt u. Gliederung einer Grundlinie in d. Morphologie Ostasiens": *Peter. Mitt.*, vol. xlvii, 1901, pp. 140–2; "Die geol. Bild. Centralasiens u. Chinas": *Verh. Naturw. Ver. Karlsruhe*, vol. xiii, pp. 205–8.

F. Leprince-Ringuet[1] in 1898–9, acting on the instruction of the French Ministry of Foreign Affairs, made observations in the Shan-si coal-field, and dealt to some extent with the general structure of Northern China. The stratigraphical results obtained by Lorenz[2] from his field-study in Shan-tung and from his palæontological research are distinctly of scientific value. Vogelsang's[3] report on his journey in northern Chi-li and western Hu-peh contains useful data for petrographical and tectonic study.

While these writers intermittently pursued their researches, Richthofen was all the time publishing original papers and parts of his epoch-making work *China*. Unfortunately he did not live to complete the latter. A few years before Richthofen's death Dr. Bailey Willis was appointed to take charge of the Carnegie Expedition. After a discussion with Richthofen of a most profitable route for the expedition, Bailey Willis and E. Blackwelder carried out a reconnaissance in western Shan-tung, southern Manchuria, the adjoining districts of Chi-li and Shan-si, central Shan-si, the bordering area between Shen-si, Su-chuan, and Hu-peh, and the Yang-tze Gorges. They obtained much valuable information[4] within a relatively short period of time. Dr. Willis recognizes several physiographic stages in Northern and Central China from a geo-morphological point of view. The application of this method is especially fascinating for the study of Chinese geology, not because of its novelty to some geologists, but because of the fact that China has been essentially a continental country since the latter part of the Jurassic period; and therefore we are forced to look into the successive stages of erosion instead of merely relying upon the meagre record of deposition. As a summary of the results obtained by the Carnegie Expedition and by the previous workers, Dr. Willis published a comprehensive but somewhat hypothetical account of the *Systematic Geology of China*.

As to the south-western provinces, our geological knowledge is almost exclusively due to the labours of French explorers.[5] Beginning

[1] Leprince-Ringuet, "Etude géol. sur le nord de la Chine": *Ann. d. min.*, sér. ix, vol. xix, 1901, pp. 346–429.

[2] Th. Lorenz, "Beitrage z. Geol. u. Palaeont. v. Ostasien unter besond. Berück. d. Prov. Shan-tung in China": *Zeits. d. d. Geol. Gesell.*, vol. lvii, pp. 438–97, and vol. lviii, Aufsätze, pp. 53–107.

[3] K. Vogelsang, "Reisen in nord. u. mittl. China": *Peter. Mitt.*, vol. xlvii, pp. 241–78, and vol. l, pp. 11–19.

[4] Bailey Willis, *The Research in China* (1903–4), Carnegie Institution.

[5] Leclère, *Etude géol. et. minière d. prov. chinoises voisines du Tonkin.* Monod, "Contribution à l'étude géol. d. prov. merid. de la Chine": *Bull. économ. Indo-Chine*, vol. iv, pp. 619–37; "Annonce l'existence de la huille devonienne, etc.": *C.R. Acad. Sci.*, vol. cxxxii. pp. 270–2. H. Lantenois, "Note sur la géologie et les min. de la région comprise entre Lao-kay et Yunnan-sen": *Ann. d. min.*, sér. x, liv. iii, pp. 300–84, and liv. iv, pp. 385–503, 1907. A. F. Legendre, "Massif Sino-Thibétain, Province d. Setchouen, d. Yunnan et Marches thibétaines; "de la géologie d. pays Lolo": *Bull. Mus. d'hist. nat. d. Paris*, 1910, No. 1, pp. 59–62. J. Deprat and H. Mansuy, "Etude géol. d. Yunnan oriental": *Mem. d. Service géol. d. l'Indo-Chine*, 1912–13.

with the expedition of the Me-kong, there followed the missions of Leclère and Lantenois. The recent research of Dr. J. Deprat has brought many points of scientific interest to light. His establishment of the Fusulinidæ zones for the marine Carboniferous and Permian is likely to assume universal importance. His report on the geology of eastern Yun-nan is particularly notable in its precision and lucidity.

So much for the history of geology in China. Now we come to the geological history of China. In dealing with such a stupendous subject as this, one may be sure at the very beginning that it is impossible to enter into details in this short paper. Moreover, the fragmentary nature of our present knowledge must naturally necessitate the introduction of risky assumptions and hypotheses in attempting to form a connected view of the successive geological changes that have taken place in the vast area of eastern Asia since Archæan time. Nevertheless, we feel the pressing need of linking up, so to speak, the available authentic information so that some ideas may be obtained as to what has been done in the past and what is to be done in the immediate future. This paper is, therefore, primarily meant to be a synthetic review of the existing literature rather than a summary of critical analyses of the same. Only those points which appear to be of utmost importance are raised and briefly discussed.

The General Structure of China.

China Proper may be divided, for the convenience of a broad tectonic consideration, into two parts of approximately equal dimension, between which runs the long range of the Tsing-ling from west by north to east by south. The area to the north of this range or Northern China is further divisible into three parts of different structure.

1. In the north-eastern area there occur parallel folds principally running north-east or east-north-east, and occasionally accompanied by secondary undulations with their axes running east to west.[1] The Palæozoic rocks are in many places involved in these folds; while the Jurassic are apparently free from their influence. In the mountains of north-western Chi-li the north-east folds are so remarkably well developed that after a glance at Richthofen's geological map one can hardly fail to appreciate the meaning of his appropriate term the "Grid of Peking".

2. In the north-western area we find a series of high mountains, the Nan-shan Ranges, running from north-west to south-east, and gradually bending in between longitudes 103°–104° E., into arcs with their concave side facing the north, i.e. more or less concentric with the Irkutsk-Amphitheatre of Suess. The tectonic axes of the Nan-shan Ranges generally agree with the mountain trend except for Mesozoic synclines that in some cases obliquely traverse the ranges.

[1] F. N. Drake, "The Coal-field of North-East China": *Trans. Amer. Inst. Min. Eng.*, 1901–2, pp. 492–512.

3. The central area comprises the provinces of Shan-si, Shen-si, and a part of Kan-su, and constitutes a huge barrier which arrests or deflects the waves of folds coming from the north-east and the north-west. The eastern part of the central block, namely, the province of Shan-si, with gently inclined Palæozoic and Triassic (?) strata, is divided up by mighty faults running more or less in parallelism with the Fen-ho valley. Towards the south-western corner of the province of Shan-si, where the Hwang-ho suddenly sweeps round from a north–south course to east-north-east, the faults look as if being progressively compressed till a single line of fracture, the Wei-ho fault, takes their place. The latter extends for a considerable distance along the northern foot of the Tsing-ling Range.

Tectonically related to but physiographically separated from the "table-land of Shan-si" is the province of Shan-tung, which Suess justly discusses as a "shattered horst".

In Southern China, or the area to the south of the Tsing-ling Range, large tectonic units are not so readily recognizable as in the northern part of the country. Nevertheless, we can make use of certain prevailing structural features so as to render an equally broad analysis possible.

1. Let us begin with the mountainous region of western Su-chuan. There highly compressed parallel folds run predominantly from the north to the south. On reaching northern Yun-nan the folds tend to open out, that is to say, they appear to bend slightly round the Tibetan Plateau on the one side and follow the elbow of the Yang-tze on the other.

2. Immediately to the east of the north–south folds of western Su-chuan and to the south of the Tsing-ling Range, a plain known as the Great Red Basin of Su-chuan spreads itself out over a considerable area. The basin is filled up by a formidable sequence of Mesozoic and post-Mesozoic strata folded, in its south-eastern part, into a series of sharp anticlines with their trend varying from north-east to north-north-east.

3. South-Eastern China, or the area to the east of the Yang-tze Gorges and the Kwei-chou Plateau, appears to descend from the highland of South-Western China by a gigantic step either in the form of a flexure or fractures, or probably both. If the line indicating the "Hoa-kiang Flexure" (extending from about long. 106° 40′ E., lat. 25° N. to the north-east) of Leclère [1] be produced to the north-east, it would significantly pass along the eastern edge of the Kwei-chou Plateau,, where signs of a powerful dislocation have been witnessed by Wingate,[2] and would fall in line with the axis of the Hwang-ling Anticline in western Hu-peh or the gorge district of the Yang-tze. It is interesting to compare this line of disturbance with the eastern edge of the Shan-si Plateau and the Great Khingan

[1] Leclère, op. cit., pl. xiii.
[2] *Geogr. Journ.*, 1899, p. 639 et seq.

"step" by which Mongolia descends to Manchuria. They curiously reveal a harmonious relation, and may indeed be genetically related. In the vast area of South-Eastern China the rocks are generally folded in a north-easterly direction, reminding us of the structure of the north-eastern part of the country. What specially calls for our attention in this area is the zone of igneous activity which defines the south-eastern coast, and which is singularly parallel to the hypothetical line of disturbance along the eastern edge of the Kwei-chou Plateau as already discussed.

The Fundamental Complex.

Rocks of extremely complex composition and structure are frequently reported to occur in Northern China. They form the greatest part of the Liao-tung and the Shan-tung peninsulas. Richthofen maps them as the "old gneiss and gneiss-granite", and regards them as Archæan.[1] Rinne[2] and Lorenz, however, consider much of the so-called Archæan gneiss in Shan-tung as Algonkian granite. In other provinces of North-Eastern China schists and gneiss of very ancient type are often exposed in the mountain ranges. They are found, for instance, in the mountains to the west of the Liao-ho valley and in the neighbourhood of the great lava field of southern Mongolia. From the vicinity of the Wutai-shan (to the north of lat. 39° N., between longs. 112° 30′ E. and 114° E.) they dive towards the south, and reappear in the lower parts of the mountain ranges that stand on both sides of the Fen-ho valley.

Further south a belt of Archæan gneiss runs along the northern foot of the Tsing-ling Range, and spreads itself out towards the east, namely, in the provinces of Ho-nan, northern An-hwei, and north-eastern Hu-peh. In these places the Archæan gneiss and schists sometimes rise as rugged mountains, and sometimes form plains partially covered by the "Hwang-tu" or the Loess.

In the north-western part of the Nan-shan Ranges, namely, in the principal chains lying to the south-west of the Da-ssue-shan or the Great-snow-mountain (extending from about lat. 40° N., long. 96° E. to the south-east), such as the Yema-shan, the Humboldt Mountain, and the South Tsaidam-ula or the Muschketov Range, Obrutchov found ancient gneiss and crystalline schists occurring in association with a variety of intrusive masses. The former class of rocks probably includes Archæan representatives.

The petrological characters of the above-mentioned Archæan rocks are so widely different from one another that a generalized description is hardly of any use. Suffice to say that they are not, as a whole, petrologically unlike the Lewisian of Great Britain and the Fundamental Complex of North America. Willis and Blackwelder, therefore, term the gneiss and schists that they observed in the

[1] *China*, vol. ii, p. 706.

[2] "Beitrag zur Gesteinskunde des Kiau-tschou": *Zeits. d. d. geol. Ges.*, Aufsätze, pp. 122–67.

adjoining area of Chi-li and Shan-si and in the Tai-shan districts, western Shan-tung, the Tai-shan Complex. Further, they distinguish in the Tai-shan Complex at least three groups of rocks: the oldest consists of a chaotic mass of hornblende-schist, mica-schist, chlorite-schist, and other highly altered rock material that may have been derived from true aqueous deposits. In the Complex are found large intrusive bosses of acid composition, accompanied by offshoots of pegmatite, aplite, quartz-veins, etc. These are in general highly altered or strained. The youngest is a group of basic dykes, which are sometimes metamorphosed into true schist and sometimes remain unaltered.

In Southern China old gneiss and schist that can be definitely attributed to the Fundamental Complex are so far unknown. Schists and gneiss are reported to occur in the coast of Fu-kien [1] among the igneous intrusions and extrusions. But sufficient data are not yet available for the determination of their stratigraphical position.

(*To be continued.*)

The Lower Carboniferous Chert Formations of Derbyshire.[2]

By H. C. Sargent, F.G.S.

(PLATE IV.)

Introduction.

THE origin of chert has of late been discussed with renewed activity, especially in American scientific journals. Difference of opinion centres mainly round the question of the source of the silica; whether it is of direct inorganic origin, or the result of the solution and redeposition of organic silica. Further points at issue relate to the age and formation of the chert; whether it is an original deposit contemporaneous with the country rock, or a metasomatic replacement of the latter and therefore of later age.

The object of this paper is to discuss the evidence afforded by the chert formations of Derbyshire, and to state the conclusions which are believed to be indicated as to their origin. Such conclusions are, in brief, as follows:—

(1) The cherts of Derbyshire are believed to be of direct inorganic origin, and not derived to any considerable extent, if at all, from organic silica.

(2) They appear to have been mainly deposited contemporaneously with the country rock, and are not, except to a limited extent, a metasomatic replacement thereof.

Rare occurrences are of later age.

[1] Ishii, "The Geology of the Yang-tze Valley": *Bull. Imp. Geol. Surv. Japan*, vol. xxiii, No. 2.

[2] This paper is the substance of one read before the Geological Society of London, February 25, 1920, publication of which was declined (*Abs. Proc. Geol. Soc. Lond.*, No. 1,051, pp. 47–8). Some additional evidence is now introduced.

General Description.

The chert of Derbyshire occurs mainly in the upper beds of the Carboniferous Limestone throughout the entire outcrop, and also in the clays and thin limestones passing up into the Limestone Shales. The chert-bearing limestone is usually thin-bedded, dark or black in colour, and belongs to subzones D_3 and D_2 of Vaughan's classification.[1] Sporadically, feeble developments are found in the massive, white or pale D_1 limestone at a considerable distance below the main beds.

Sometimes, especially in the northern part of the outcrop, the main chert-bearing limestone is pale-grey or white, and loses its thin-bedded character.

The chert occurs either as rows of nodules of very varying size and shape, or as tabular sheets up to 8 or 10 inches thick and of considerable horizontal extension. Rarely it may be seen filling vertical fissures or joints in the limestone.

A feature that has an important bearing on origin is the frequent change of horizon at which the chert-bearing limestone sets in. In the neighbourhood of Matlock, Cromford, and Crich it is only from 50 to 60 feet thick, but near Middleton Moor, about 2 miles south-west of Cromford, it sets in 150 feet lower, replacing pale, massive, chertless limestone. At Ashover the thickness is about 150 feet and on the western side of the massif it may attain 400 feet.[2] Between Longstone and Buxton the chert-bearing beds are 450 feet thick.[3]

The transition from the pale, massive limestone to the overlying dark, thin-bedded, chert-bearing rock is usually extremely abrupt.

In addition to the main chert deposits described above, there are other occurrences distinctly local in distribution which require separate mention. They are found mainly in the neighbourhood of Bakewell and to the west and north-west of that town, at Ashford and near Longstone Edge. These cherts consist of massive beds sometimes 8 or 9 feet thick, and they are usually white or grey without any relation to the colour of the associated limestone.

Similarly, on the north-west of Crich Hill there is a development of massive, brown chert of which 6 feet in thickness are exposed, but the base is not seen. It can be traced round the north side of the hill, and reappears on the east near the Old End Mine.

It is believed that these beds of massive chert owe their silica to a different source from that of the main chert beds.

In colour the cherts, other than the massive beds just referred to, generally bear a close relationship to that of

[1] Cf. "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, 1913, pp. 13–14.

[2] Most of these details of thickness are taken from "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, 1913, p. 20.

[3] T. F. Sibly, "The Faunal Succession in the Carboniferous Limestone of the Midland Area": *Quart. Journ. Geol. Soc.*, vol. lxiv, 1908, p. 38.

the associated limestone. It varies from white to grey, blue and black, being as a rule, but no means always, darkest in the darkest limestone. The pigmenting agent appears, without doubt, to be generally organic carbon. The following partial analyses of five specimens of Derbyshire chert have been kindly prepared by Dr. H. F. Harwood and Mr. S. Young, of the Imperial College of Science and Technology. Owing to the varying amounts of limestone inclusions and calcareous organisms in most cherts, complete analyses possess little value.

	I	II	III	IV	V
Fe (as Fe_2O_3)	0·02	0·60	0·05	0·42	0·26
CO_2	Not est.	—	Not est.	0·40	1·66
Org. C	—	0·09	0·32	0·54	0·33

I. White massive chert, Ashford.
II. Brown massive chert, Crich Hill.
III. Black nodular chert, Dale Quarry, Wirksworth.
IV. Black nodular chert, Klondyke Quarry, Crich.
V. Pale-grey nodular chert, Intake Quarry, Middleton.

These analyses show a consistent relationship between colour and percentage of carbonaceous matter, except in No. V, a pale-grey rock, in which the carbon is segregated into minute flakes visible under a pocket-lens.

The percentage of iron does not show the same consistent relationship to colour except in the case of No. II, a brown chert nearly free from other impurity. It is not, however, uncommon to find black nodules with the weathered surface oxidized to a rusty brown. It is, therefore, possible that ferrous iron may sometimes be the colouring agent.[1]

Evidence of Contemporaneity.

All the tabular sheets of chert are conformably interstratified in the limestone with which they are associated. They are never transgressive. When the thickness of a bed varies, swelling or contracting, as is often the case, within a short distance, the bedding planes of the overlying rock always conform to the surface of the chert. Similarly, the rows of nodules are always aligned parallel to the bedding of the limestone. Isolated nodules often occur between the rows, but this is not a case of transgression.

When lenticular or current bedding of the limestone has taken place, converging rows of nodules or thin sheets of chert may be seen following the bedding planes. Good examples of this feature occur in Intake Quarry near Middleton, in Wensley Dale, and in Bradwell Dale.

The nodules usually occur in solid limestone away from partings. In vertical section their longer axes are almost always parallel to the bedding. When they occur in laminated, shaly limestone the

[1] C. S. Garnett has shown that the colour of "Blue John" is due to bituminous matter (*Trans. Chem. Soc.*, vol. cxvii, 1920, pp. 621–3).

bedding lines of the overlying rock curve over the nodules, showing clearly that the latter were in situ before it was deposited (Fig. 1).

Under similar conditions the bedding lines of the rock below a nodule are disturbed to conform with the irregular under-surface of the nodule (Fig. 2). The last feature appears to prove that the chert had consolidated more rapidly than the calcareous ooze into which it was pressed down.

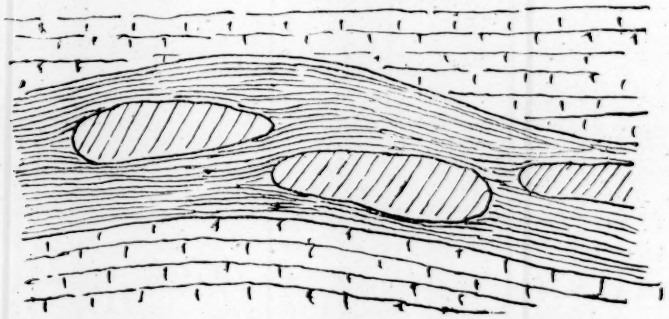

FIG. 1.—Chert-nodules in shaly, laminated limestone, Shiningbank Wood, near Alport. Solid limestone above and below the shaly bed.

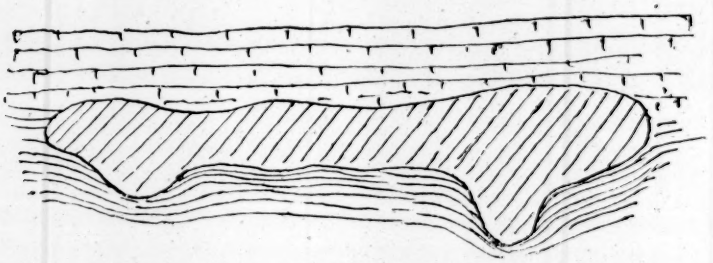

FIG. 2.—Chert-nodule, Lovers' Walk, Matlock Bath. Solid limestone above, shaly, laminated limestone below the nodule.

Cracks in the nodules, or sheets, are often filled with limestone, which appears to be obviously contemporaneous with the enclosing rock.[1]

It may often be seen that the upper surface of a sheet of tabular chert is quite level, as if spread out by currents, and contrasting strongly with the irregular lower surface. A rough flow-structure may sometimes be seen in thin sections.

Contemporaneity is not claimed for chert filling fissures or joints in the limestone. Such occurrences are rare in Derbyshire, and they appear to be clearly of later formation. In the few instances

[1] Cf. W. A. Tarr, "Origin of the Chert in the Burlington Limestone": *Amer. Journ. Sci.*, vol. xliv, 1917, p. 422.

noted by me, crystalline calcite is associated with the silica in the fissure.

Petrology of the Silica.

It is generally recognized that the silica composing chert was originally in colloidal form. It has subsequently passed over mainly into crypto- or microcrystalline material, but a more coarsely crystalline development (quartz or chalcedony) is also of common occurrence.

Lindgren [1] points out that the work of Heim, Leitmeyer, and others leads to the conclusion that chalcedony is in all cases composed of quartz fibres, and that it always results from crystallization of gelatinous silica, which may, in becoming crystalline, either turn into granular quartz or into fibrous quartz, i.e. chalcedony.

Impurities in the silica appear to have had a marked effect on its crystallization. In the dark-coloured or black cherts the development is mainly crypto- or microcrystalline, but small areas, of varying shapes, may often be seen in thin sections from which the impurities appear to have been drawn off by segregation, or which have, perhaps, been left clear by differential absorption. In the clear central portion of such areas granular quartz has formed. On the outer margin of the quartz there is usually a narrow zone of fibrous quartz (chalcedony), often in the form of radial aggregates. Its refractive index is always a little lower than that of the granular quartz (Becke's test). Outside this zone, in the more highly pigmented matrix, the silica is crypto- or microcrystalline.

When viewed in thin section by transmitted light, the chalcedony is frequently, but not always, of a pale-brown colour. Pirsson [2] has shown that this colouration, which often occurs in felspar-spherulites in acid lavas, may be an optical phenomenon due to absorption of the blue rays in passing through angular fibres or scales of a colourless mineral; the finer the fibres the greater being the absorption. This is, perhaps, often the case in the rocks under discussion, but the chalcedony is also frequently coloured by a ferruginous or bituminous pigment, which is occasionally concentrated in concentric bands (Pl. IV, Fig. 1).

It is noteworthy that in the purer cherts, nearly or quite free from colouring matter, although some of the silica may remain in the cryptocrystalline state, there is no chalcedony, but an extensive development of granular quartz.

Liesegang [3] has shown that the presence of iron hinders crystallization in agates, and the foregoing considerations seem to justify the same conclusion in regard to impurities in chert.

[1] "Processes of Mineralization and Enrichment in the Tintic Mining District": *Econ. Geol.*, vol. x, 1915, p. 233.

[2] "On an Artificial Lava-flow and its Spherulitic Crystallization": *Amer. Journ. Sci.*, vol. xxx, 1910, pp. 101–2.

[3] *Geologische Diffusionen*, 1913, p. 100.

Evidence against Metasomatism.

Much of the evidence already given in favour of contemporaneity is also obviously opposed to the theory that the chert is a pseudomorph. There are other considerations that tend in the same direction, although the microscope shows that a limited amount of replacement has generally taken place at the contact between chert and limestone. It is obvious, however, in thin sections that impurities have not only hindered crystallization, but also, to a large extent, replacement.

In the dark or black cherts the replacement is usually limited to a thin band of clear crystalline silica at the contact between chert and limestone or around calcareous organisms (Pl. IV, Fig. 2). The calcite of small organisms, perhaps as a result of freedom from impurity, is sometimes entirely replaced, but unsilicified calcareous fossils are very abundant. Dr. G. J. Hinde[1] called attention to these features as disproving the pseudomorph theory.

The contact between chert and limestone is usually quite sharp and often serrated (Pl. IV, Fig. 3). The nodules, when black, often break away from the enclosing rock with a clean fracture, making it difficult to obtain a hand-specimen showing the contact.

In the purer white cherts, on the other hand, there is usually no definite line of contact, but a broader transition zone in which the replacement reaction appears to have been active, and in which crystalline silica and calcium carbonate are intimately intermingled.

Wherever this partial replacement has taken place, the replacing material is clear crystalline silica, probably always in the form of minutely granular quartz. The impurities appear to be always excluded from the contact films of the solutions that take part in the reaction.[2]

It is significant that in the quartz-rock described by Dr. Bemrose,[3] which, as he states, is clearly a replacement of limestone, there is no amorphous or cryptocrystalline silica, no chalcedony, and the replacing silica is all in the form of clear granular quartz.

The conclusion seems to be justified that the impure silica of these cherts, which remains in a crypto- or microcrystalline state, has taken no part in a replacement reaction with calcium carbonate.

If the pseudomorph theory be true, thin partings in laminated limestone, consisting of detrital terrigenous material (Fig. 1), should be repeated in the chert, since they would obviously not be replaced by the metasomatic reaction. There is no such repetition.

Minute grains of calcite may often be seen associated with the quartz in the partial replacement zone. This probably indicates that the consolidation of the silica took place before the calcite grains were completely replaced, and they were thus preserved from

[1] "Organic Origin of Chert": Geol. Mag., 1887, p. 445.

[2] Cf. Lindgren, *Mineral Deposits*, 1913, p. 671; also Tarr, op. cit., p. 415.

[3] "On a Quartz-rock in the Carboniferous Limestone of Derbyshire": *Quart. Journ. Geol. Soc.*, vol. liv, pp. 169–83.

further action by the solutions. Other evidence leading to the conclusion that the chert was consolidated more rapidly than the limestone has already been given, and it is clear that rapid dehydration and consolidation would quickly limit replacement.

Professor A. H. Church,[1] in his well-known experiment, found that gelatinization of silica stopped the reaction between silicic acid and calcium carbonate if the concentration of silica in the solution exceeded 0·15 per cent.

The occurrence of chert in the clays at the top of the limestone shows that replacement is not an essential feature of its formation.

The invariable conformity of the limestone with the sheets of tabular chert, even to small details of undulating surfaces, appears to be quite inconsistent with the view that the chert is a pseudomorph.

Evidence against the Sponge-spicule Theory.

The theory of the solution and redeposition of organic silica, although nearly unanimously rejected by recent American investigators, still finds support among English geologists.[2] It is proposed to examine the conflicting evidence.

It seems clear that these extensive contemporaneous beds of chert were rapidly formed, and it is admitted by supporters of the theory that an agent capable of effecting the solution, and likely to be present in the sea, is unknown.

Remains of unsilicified calcareous organisms, as already noted, are abundant in the chert, and hence it is clear that acids generated by decaying organic matter were of no great importance as solvents.

The alkaline reaction of sea-water above a calcareous ooze is believed by some[3] to be capable of dissolving organic silica. This may, perhaps, be the explanation of the replacement of sponge spicules, more or less completely, by calcite in limestone, but never in a cherty matrix.[4] It seems certain, however, that a considerable period of time would be required for the process. The solution actually observed in sponge-spicules from modern dredgings is limited to a widening of the axial canal and the disappearance or thinning of more delicate processes.[5]

Spicules, of which the amorphous silica has become crystalline, are abundant in many thin sections of both chert and limestone, and it seems obvious that if solutions capable of dissolving organic silica were present to the extent necessitated by the theory, it is hardly likely that any spicules would be preserved.

[1] "Observations on Silica": *Journ. Chem. Soc. Lond.*, vol. xv, 1862, p. 109.

[2] Cf. E. E. L. Dixon, *Abs. Proc. Geol. Soc. Lond.*, No. 1,051, 1920, p. 49.

[3] Cf. E. F. Davis, "The Radiolarian Cherts of the Franciscan Group": *Univ. Cal. Pub. Bull. Dep. Geol.*, vol. xi, 1918, p. 366.

[4] Cf. G. J. Hinde, "On Beds of Sponge Remains in the Lower and Upper Greensand of the South of England": *Phil. Trans.*, pt. ii, 1885, p. 431.

[5] Murray and Irvine, "On Silica and the Siliceous Remains of Organisms in Modern Seas": *Proc. Roy. Soc. Edin.*, vol. xviii, 1891, p. 231.

Davis[1] calls attention to the very important point that the radiolarian earths of Barbados are believed to represent true deep-sea siliceous oozes, yet there is no evidence of the solution of silica on the sea-floor, and these siliceous organic remains have not been converted into chert. He also points out that the white diatomaceous earths of the Monterey group in California, which must have been associated with much organic matter, are almost unconsolidated and show no evidence of solution.

Dr. F. W. Clarke[2] states that the silica extracted from the ocean by radiolarians, diatoms, and siliceous sponges "is finally deposited on the sea-floor and does not redissolve, or at least not readily". He adds: "The insolubility of silica in sea water is great but not absolute."

Source of the Silica.

The formation of chert by direct chemical precipitation of inorganic silica held in solution in sea-water, which is supported in this paper, has found many advocates in the past. Among these may be mentioned Hull and Hardman,[3] Prestwich,[4] and, more recently, Tarr,[5] Van Tuyl,[6] and, in part, Twenhofel.[7]

Upwards of 319,000,000 metric tons of dissolved silica are annually contributed to the sea in colloidal form by the rivers of the world.[8] Yet the amount present in normal sea-water is practically *nil*. This fact clearly indicates, as Tarr[9] and Twenhofel[10] point out, the completeness of the precipitation.

Within the area of the deposition of muds and fine silts the dissolved silica appears to be carried down and to form a large part of the colloidal constituent, giving plasticity to clays.[11] Ashley has shown in an important paper that the colloidal matters of clay are "non-crystalline, hydrated, gelatinous, aluminum silicates, organic colloids, gelatinous silicic acid, and hydrated ferric oxide".[12]

Dr. W. T. Gordon has kindly pointed out to me that E. C. Barton[13] has shown the importance of colloids, acting as an agglutinant, in the formation of sandbanks and deltas. He states:

[1] Op. cit., p. 370.

[2] *The Data of Geochemistry*, 1916, p. 130.

[3] "On the Nature and Origin of the Beds of Chert in the Upper Carboniferous Limestone of Ireland": *Sci. Trans. Roy. Dub. Soc.*, vol. i, 1878, pp. 71–94.

[4] *Geology, Chemical, Physical, and Stratigraphical*, vol. ii, 1888, pp. 320–4.

[5] Op. cit., p. 427 et seq.

[6] "The Origin of Chert": *Amer. Journ. Sci.*, vol. xlv, 1918, p. 456.

[7] "The Chert of the Wreford and Foraker Limestones along the State Line of Kansas and Oklahoma": *Amer. Journ. Sci.*, vol. xlvii, 1919, pp. 407–29.

[8] F. W. Clarke, *Data of Geochemistry*, 1916, pp. 115–16.

[9] Op. cit., p. 429.

[10] Op. cit., p. 417.

[11] Cf. Leith and Mead, *Metamorphic Geology*, 1915, p. 104.

[12] "The Colloid Matter of Clay and its Measurement": *U.S. Geol. Surv. Bull.* 388, 1909, p. 12.

[13] "The Work of Colloids in Sandbank and Delta Formation": *Geogr. Journ.*, vol. li, 1918, pp. 100–12.

"Professor E. W. Hilgard found, at the mouth of the Mississippi, a 15 feet layer of colloidal jelly on the ocean side of the bar. He ascribes its formation to the precipitation of the fine colloidal particles by the mixing of the river waters with the salt water" (*Pop. Sci. Monthly*, March, 1912). I have been unable to obtain access to Professor Hilgard's paper.

The effectiveness of the ions of bivalent elements in causing flocculation has been shown to be much greater than that of univalent ions, and it has been conclusively proved experimentally that colloidal silica is rapidly flocculated and precipitated by calcium carbonate in presence of carbon dioxide.[1]

In a sea in which deposition of calcium carbonate was continuously taking place simultaneously with the products of land-erosion, as was the case when the impure chert-bearing limestones of Derbyshire were laid down, there can be little doubt that dissolved silica would be contributed to the sea, and that it would be precipitated near the land when a sufficient concentration had taken place. The tendency of silica to form supersaturated solutions is an important point.

The purer white, or pale, lower limestone, in which chert occurs sparingly and sporadically, was probably formed in a clear sea, not necessarily far from land, but under conditions when the contribution of dissolved silica, or other terrigenous material, was exceptional and not the rule.

The liberation of silica by carbonation of silicates would be greatly increased, as was pointed out by Prestwich,[2] and more recently by Van Hise,[3] if the area undergoing denudation consisted of basic igneous rocks. The abrupt transition in many parts of Derbyshire from the pale or white limestone to the overlying, impure, chert-bearing rock is very noteworthy, and would, of itself, suggest that movement, resulting in an increase of terrigenous deposits, had taken place. This view is strongly supported by the presence, as observed in the field, of small unconformities and thrusts, and occasional current-bedding.[4]

The toadstones of Derbyshire often underlie the main chert-bearing rock at no great distance, and it is suggested as very probable that some, perhaps a large part, of the sea-floor covered by these submarine flows was raised above sea-level by disturbance, and was thus brought within the range of atmospheric and chemical erosion. There seems, therefore, to be fair evidence that, during the deposition

[1] Cf. Dean, "The Formation of Missouri Chert": *Amer. Journ. Sci.*, vol. xlv, 1918, p. 413. Also Tarr, op. cit., pp. 434–6.

[2] Op. cit., p. 324.

[3] "A Treatise on Metamorphism": *U.S. Geol. Surv. Mon.* 47, 1904, p. 824. See also Van Hise and Leith, "The Geology of the Lake Superior Region": *U.S. Geol. Surv. Mon.* 52, p. 505.

[4] Cf. T. F. Sibly, op. cit., p. 63 and fig. 5 (p. 62). Also C. B. Wedd, "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, p. 35, 1913. The author has noted unconformities in other parts of the limestone massif.

of the main chert-bearing limestone, a large supply of dissolved silica was available for the formation of chert. The variations in the horizon at which the chert-bearing limestone sets in, as noted above, may be attributed to differential movement on the sea-floor.

There is abundant evidence of the simultaneous precipitation of silica and calcium carbonate. At Knivetonwood, about three miles north of Ashbourne, nodules of black chert, in clays at the top of the limestone, have a brown rind, from $\frac{1}{4}$ to $\frac{3}{8}$ in. thick, consisting of an intimate admixture of calcium carbonate and cryptocrystalline silica, the latter being present in one specimen examined to the extent of 14 per cent. The limestone associated with chert in the same quarry weathers brown like a sandstone. In a specimen of this rock the insoluble residue, consisting largely of cryptocrystalline silica, amounted to 39·5 per cent. In the Black Marble Quarry, at Ashford, there is a strong development of black chert in thin sheets, on which there is a black calcareous rind similar to that on the Knivetonwood nodules.

The colour-relationship between chert and limestone, resulting from similar impurities, and the nearly simultaneous setting in of the chert with the change of character of the limestone, at whatever horizon the change takes place, are further indications of the close connexion between land-denudation and chert-formation.

A feature very often seen in thin sections of chert is the presence, often in great numbers, of minute rhombs of dolomite or chalybite, the latter often oxidized to opacity. The absorptive property of colloids affords a simple explanation of the presence in the colloidal silica of metalliferous salts, the products of contemporaneous chemical denudation, which have subsequently crystallized out as dolomite or chalybite. It is difficult to understand how this feature can be reconciled with the sponge-spicule theory. Further, the chert in which the rhombs occur is sometimes embedded in limestone, which is not dolomitized, and contains no rhombs. This feature seems quite inconsistent with the theory that the chert is a pseudomorph.

The occurrence of chert in nodules, of very varying shape and size, and often with patches of limestone enclosed, points to segregation subsequent to precipitation. Twenhofel[1] observes that the dominating factor in nodule-growth was the attraction exercised on the dissolved silica by the growing nodule. The occurrence of a calcareo-siliceous rind on nodules or sheets suggests that there was a heavy simultaneous precipitation of calcium carbonate, and that diffusion of the silica was arrested by dehydration and consolidation.

The variation in vertical spacing between different rows of nodules or sheets, ranging from a few inches to several feet, suggests variation in the time required to effect a sufficient concentration of silica

[1] Op. cit., p. 427.

for precipitation, owing to differential denudation. This feature would be difficult to explain under the sponge-spicule theory.

Davis [1] has shown experimentally that when a suspension of finely divided clay was mixed with a solution of sodium silicate, the addition of ammonium carbonate caused flocculation of silicic acid and formation of gelatinous silica. The silica and clay were segregated into alternate layers, and it is interesting to note that the experiment produced many of the features of the bedding of chert, such as nodules, irregular thinning and thickening of bands and lens-like terminations.

The massive cherts, referred to above, which are of purely local occurrence, now require consideration. These rocks, so far as existing exposures show, occur solely in the neighbourhood of former volcanic activity. Near Bakewell they are closely associated with the Cracknowl (or Crackendale) vent, and they overlie the lava of that district. At Crich there is a bed of lava in the hill, at some distance below the chert. Wherever they occur they are seen on one horizon only, and are not repeated again and again through a considerable thickness of limestone, as is the case with the main chert beds. It would appear that the supply of silica was continuous till it was exhausted.

The absence or paucity of organic colloids (see Analyses I and II) is a noteworthy feature, distinguishing these rocks from the main chert beds. The result appears to be that, in colour, they show no relationship to the associated limestone. White is the prevailing colour, but grey beds are often interspersed. The Crich rock is brown, owing to admixture of iron. Not infrequently the rock has the appearance of a sinter, resembling the present-day deposits of hot springs. Fluorite is frequently associated with these cherts, as it is with quartz-rock. It occurs as the infilling of cavities and veins, and in minute grains scattered through the rock and in the associated limestone. At Ashford, a specimen of limestone from a parting in the chert contained 0·36 per cent of insoluble residue, which consisted of amorphous fluorite with a little cryptocrystalline silica.

Fossils are rare in these cherts. That organisms were sometimes entangled in the silica is rendered probable by the occasional occurrence of flakes and small concretions of carbonaceous matter, but it is rarely that any trace of the organism remains.

As with the main cherts, so, too, with those under consideration, simultaneous precipitation of silica and calcium carbonate has often taken place. Streaks and patches of limestone are common in thin sections, their margins usually showing signs of replacement (Pl. IV, Fig. 4), and short discontinuous bands, 3 or 4 inches thick, may be seen in the body of the rock.

[1] Op. cit., pp. 399–401.

The lava-flows underlying these beds have suffered intense decomposition, which must have liberated large quantities of silica. It has been shown elsewhere [1] that the orthoclase and albite molecules were conspicuously present. Lindgren [2] states that in the great geyser regions of Yellowstone National Park, New Zealand, and Iceland the predominating springs "are essentially sodium chloride waters with large amounts of silica, believed to exist in part as sodium silicate, a large quantity of free carbon dioxide, and a little hydrogen sulphide". "The waters are always hot and usually ascend through volcanic rocks."

The features of the massive cherts of Derbyshire, which distinguish them from the main cherts, suggest a different origin, and it is believed that pneumatolytic discharges from the cooling lava-flows, or juvenile waters, the expiring manifestations of volcanic activity, may have carried similar salts and been the direct source of the silica of which they are composed.[3] It is suggested that these rocks may, for distinction, be conveniently named "magmatic cherts".

Banding of the Cherts.

In all the cherts a banding, consisting of alternate light and dark layers, is not infrequently seen. In the nodules the bands are generally concentric or parallel with the outer surface. In the tabular cherts they are usually parallel with the bedding planes. This feature appears to be the result of a segregation or rhythmic precipitation of impurities in the course of dehydration. The light bands often consist of clear silica, apparently free from impurities. "Alternating segregation of silica and calcite," as noted by Mr. Dixon,[4] has not been observed by me in the Derbyshire cherts.

A feature that may often be noticed in thin sections is the presence of a thin bituminous band, or string, following the line of contact between chert and limestone (Pl. IV, Fig. 3). Similar strings sometimes occur in the body of the limestone itself. Dr. Sorby [5] called attention to this feature in limestone from Stony Middleton.

So far as can be judged from thin sections and hand-specimens, the bituminous material belongs to the limestone and not to the chert. Sometimes, when there is no definite band, the limestone shows a distinctly greater depth of colour in the neighbourhood of the contact. Moreover, the band sometimes occurs at the contact between white chert, free from carbonaceous matter, and dark

[1] H. C. Sargent, "On a Spilitic Facies of Lower Carboniferous Lava Flows in Derbyshire": *Quart. Journ. Geol. Soc.*, vol. lxxiii, 1918, pp. 11–23.

[2] *Mineral Deposits*, 1913, p. 52.

[3] Cf. Dewey and Flett, "On some British Pillow-lavas and the Rocks associated with them": Geol. Mag., 1911, p. 245. Also Flett, "The Iron-ore Deposits of Nobblehouse and Garron Point and their Genesis" (Edin. Geol. Soc.) Abstract in Geol. Mag., Vol. LVI, 1919, p. 92.

[4] Loc. cit., p. 50.

[5] "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks": *Quart. Journ. Geol. Soc.*, vol. lxiv, 1908, p. 225.

obviously impure, limestone. This feature may, perhaps, be due to a draining-off of carbonaceous matter in the limestone in the course of dehydration, and, if so, it is obvious that its migration would be arrested at the contact with the more rapidly consolidated chert.

Conclusion.

It is believed that the foregoing evidence justifies the view, expressed at the commencement, that the cherts of Derbyshire are mainly of direct inorganic origin and contemporaneous with the associated limestone and clays. It is, however, possible that siliceous organisms have furnished a subsidiary source of supply, since dredgings show that organic silica is not absolutely insoluble in sea-water. It is thought, further, that the evidence shows that the chert is not a metasomatic replacement of the limestone, except to a very limited extent.

The existence of large beds composed of siliceous organisms which have not been dissolved (p. 272) is a point that cannot be ignored by advocates of the organic theory.

Although the Derbyshire cherts alone have been discussed, it is believed that the same conclusions will be found to apply to other areas. I had an opportunity last summer of making a brief examination of the fine deposits of chert in North Flintshire, which are said to extend through a thickness of 350 feet, and have been erroneously described as being without intervention of limestone.[1] At the Pentre Quarries, near Gronant, the chert occurs as tabular sheets in thin-bedded, siliceous, black limestone, the occurrence being similar to that of the beds described above at Ashford, and elsewhere in Derbyshire. After further field-work I hope, with the editor's permission, to discuss these Flintshire cherts on another occasion.

I have to thank Dr. H. H. Bemrose for kindly allowing me to examine his thin sections of chert and for much useful information as to exposures; also Dr. H. H. Thomas for kindly permitting me to examine thin sections in the collection of the Geological Survey. The interest taken by Dr. H. F. Harwood in the colour-problem has been of great service.

P.S.—Since the foregoing paper was written Mr. W. Alfred Richardson's interesting article[2] on "The Relative Age of Concretions" has appeared. The arguments in that paper seem to be mutually destructive. In Mr. Richardson's opinion, "conformity of stratification lines [round a concretion] is caused in every case by concretionary growth."[3] In the case of chert-nodules he holds to the replacement theory, and he fixes the date of their formation as "at the earliest later than the first compacting of the matrix".[2] In this case Lindgren's law of equal volumes would

[1] G. J. Hinde, "Organic Origin of Chert": Geol. Mag., 1887, p. 445.
[2] Geol Mag., March, 1921, pp. 114–24.
[3] Ibid., p. 118.

apply,[1] and since the matrix must have been removed as fast as the "growing nodule" grew, it is clear there would be no deformation of the surrounding beds!

Mr. H. L. Hawkins[2] has effectively disposed of the argument that contemporaneous concretions are never surrounded by conformable stratification lines, and it is only necessary to recall the high angle of rest, often exceeding 50 degrees, of rock-fragments on the seaward face of a coral reef, to realize that, whatever may be the results of laboratory experiments, nature does not support Mr. Richardson's view of gravitational effects on the sea-floor.

In attacking the chert-problem it is useless to deal with the nodules separately from the extensive tabular sheets which are often extremely well-bedded; a similar origin and relative age must undoubtedly be ascribed to both. Moreover, the "nodules" themselves, as seen on a vertical face of limestone, are very often merely transverse sections of branching ramifications of a large mass of chert in the interior of the rock, and not individual concretions, either spherical or ellipsoidal.

I owe Mr. Richardson many thanks for much strenuous criticism, which has been very helpful in the formation of my own views.

EXPLANATION OF PLATE IV.

(The figures are all taken from slides in the author's collection.)

FIG.

1.—Blue Nodular Chert, Nimble Jack, Via Gellia. Ordinary light, × 25 diams. (slide 565*b*). The central, white area, of irregular shape and free from impurity, consists of granular quartz. Outside the quartz fibrous chalcedony, in spherulitic aggregates, is developed in a zone of silica apparently coloured by impurity. Outside this zone the silica is crypto- or microcrystalline.

2.—Black Nodular Chert, Nutseats Quarry, near Haddon Hall. Nicols crossed, × 25 diams. (slide 577*a*). The thin, white bands are microgranular quartz, enclosing unreplaced calcareous material. In the lower left-hand portion of the figure part of the section of a coral is seen, the wall and septa being unreplaced. Granular quartz fills the spaces between the septa. The groundmass is mainly crypto- and microcrystalline silica. Oxidized crystals of a ferriferous dolomite or chalybite are seen in the figure.

3.—Black Nodular Chert, Klondyke Quarry, Crich. Ordinary light, × 20 diams. (slide 439). The black portion of the figure is limestone. The contact between chert and limestone is marked by a thin, bituminous black band.

4.—Magmatic Chert, Pretoria Mine, Bakewell. Nicols crossed, × 25 diams. (slide 573). All the silica in the section is in the form of granular quartz. The mottled grey material is unreplaced limestone.

[1] "The Nature of Replacement": *Econ. Geol.*, vol. vii, 1912, p. 529.

[2] GEOL. MAG., April, 1921, p. 192.

FIG. 1. × 25.

FIG. 2. × 25.

Photo. *G. S. Sweeting.*

FIG. 3. × 20.

FIG. 4. × 25.

[*To face p. 278.*

REVIEWS.

THE PLATINUM METALS. By A. D. LUMB. Imperial Institute Monographs, pp. ix + 63, with 1 map. London: Murray. 1920. Price 3*s.* 6*d.* net.

THIS publication forms one of the useful series of monographs on metals issued by the Mineral Resources Committee of the Imperial Institute. It comprises a full account of the world's resources, so far as known, of the metals platinum, palladium, iridium, osmium, ruthenium, and rhodium. Owing to the disturbed state of Russia and the collapse of the platinum supply, much prospecting has been carried out in other lands, but without great success. The author of this monograph has evidently followed up with great care all recent available information on the subject, and has produced a very complete account of the present state of our knowledge. Duparc's great work was, of course, not published when he wrote, but he has compiled a very good account of the platinum deposits of the Urals. Incidentally, we are pleased to see that Russian names are correctly transliterated, instead of the irritating germanized and gallicized versions that are commonly current in geological literature. To British geologists some of the most interesting occurrences of platinum are those found in association with the nickeliferous sulphides of Sudbury, Insiswa, and elsewhere. In 1918 Ontario produced nearly 5,000 troy ounces; this seems to occur as sperrylite, which is the only known native compound of platinum.

On p. 38, near the middle, we do not think that the author really means that the country rock largely consists of *olivenite*. This somewhat hypercritical remark may be permitted, since we have found the work very free from errors.

A SERIES OF NETS FOR THE CONSTRUCTION OF MODELS ILLUSTRATIVE OF THE SIMPLE CRYSTALLINE FORMS. By JAMES B. JORDAN. London: Thomas Murby & Co. 1921. Price 3*s.* net.

AS access to a set of suitable models is essential for the study of crystallography, and as models in wood are somewhat expensive, it is often helpful for the student to make use of cardboard models which he can easily construct for himself with the aid of nets, i.e. outlined drawings of the crystal faces, printed on paper or cardboard, and so arranged that they can be cut out and folded up to represent the form required.

A set of 41 nets originally drawn and published some fifty years ago by Mr. James B. Jordan, has recently been re-issued by Messrs. Murby & Co. This re-issue is welcome, and most of the nets will still be found useful, but in the interval which has elapsed since they first appeared, crystallography has made notable advances, and

a series which was adequate in 1870 is no longer as representative as is desirable. Thus, while nets of the commoner simple forms of the cubic system are given, those of the important trapezohedral form of this system—the pentagonal icositetrahedron and the tetrahedral pentagonal dodecahedron—are lacking. Similar lacunæ are found in the tetragonal and rhombohedral systems. No cubic combinations are given, and the nets of oblique and anorthic crystals illustrate a nomenclature now obsolete and could be profitably replaced by others representing actual crystals of common substances such as orthoclase, gypsum, and copper sulphate, belonging to these systems. It is to be hoped that the publishers of this series may some day see their way to giving us a revised and extended set of nets fully illustrative of modern crystallography.

THE IGNEOUS ROCKS OF ENCOUNTER BAY. By W. R. BROWNE. Trans. Roy. Soc. S. Australia, vol. xliv, 1920. pp. 1–57, with 4 plates.

THIS communication is an important contribution to igneous petrology, and adds a distinct chapter to the history of igneous action in South Australia.

The igneous rocks of Encounter Bay comprise two related series, (*a*) a plutonic series, consisting of quartz mica diorite, adamellite, potash granite, and albite mica syenite, and (*b*) a series of minor intrusions consisting of uralitic dolerites, potash aplites, soda aplite, and granophyre. The whole asemblage of rocks is to be regarded as a plutonic complex, the component members of which have been successively and more or less independently injected into their present positions from an underlying magma reservoir. The sequence of intrusion in the plutonic series is (1) quartz mica diorite, (2) adamellite, (3) potash granite, (4) albite mica syenite, the last-named rock being considered as an end product of differentiation. The facts of intrusion are best explained as due to a differentiation brought about in the underlying magma basin by fractional crystallization with sinking of crystals.

The suite of minor intrusions is considered as derived by complementary differentiation from a magma of composition closely comparable to the dominant adamellite type. The aplitic members of this complementary suite are completely free from ferromagnesian minerals. An interesting feature of the soda aplites is the development of a chequer twin structure in the albite felspar, a characteristic which appears to be widely developed in rocks of this class.

The plutonic complex is intrusive into a series of Lower Cambrian (or possibly late pre-Cambrian) sediments, which at the visible contact with the intrusive rocks are pelitic in character. The intrusions are considered to have accompanied the diastrophic movements which put an end to the Cambrian sedimentation.

A distinct metamorphic aureole surrounds the plutonic complex, and amongst the metamorphic products are andalusite and cordierite mica schists.

Pneumatolytic metamorphism of the country rocks, involving the introduction of Na_2O and TiO_2, is strongly developed near the contact with the albite syenite. This metasomatism has resulted in the production of albite hornfelses consisting of a fine-grained mosaic of quartz, albite, chlorite, and rutile. The syenite itself has not escaped metasomatic alteration, the biotite of both country rock and igneous rock being converted into chlorite.

The paper is furnished with seven complete rock-analyses, and the relations of a number of these are expressed in a variation diagram. The Encounter Bay suite of rocks forms an admirable illustration of an igneous rock series in which a progressive differentiation with increasing alkalinity is strongly emphasized.

C. E. Tilley.

Topographic Maps and Sketch Mapping. By J. K. Finch, C.E., A.M. pp. 168. John Wiley & Sons. 13*s.* 6*d.*

THIS is an elementary book on sketch mapping, and only the appendix will have much interest for the geologist. The latter consists of a descriptive list of the topographic maps of the world, special attention being given to the less well known, such as those of South America. This list will be very useful for reference, and apparently has been collected with considerable care by the compiler, F. K. Morris.

The Srimangal Earthquake of 8th July, 1918. By Murray Stuart, D.Sc. Mem. Geol. Surv. India, vol. xlvi, 1920. pp. 1–70, 12 plates.

THE Srimangal earthquake of 1918 deserved the careful investigation bestowed on it by Dr. Murray Stuart, though it is not one that has added much to our knowledge of earthquake-phenomena. The principal sections of the report are those which deal with the nature and effects of the shock within successive isoseismal lines, the analysis of the seismograms at various observatories, the secondary earthquake that occurred four or five minutes later with its epicentre near Madura in Southern India, and the results of the re-levelling across the epicentral area in the Balisera valley and in part of the Doloi valley. The depth of the focus is estimated, by Dutton's method, at about 8 or 9 miles. During the winter of 1919–20 the Trigonometrical Survey repeated a series of levels, first carried out in 1911–12, along the line from Silchar to Comilla, which crosses the epicentral area nearly at right angles to its longer axis. A comparison of the two series of levels shows that no change took place in the area to the north-east of the epicentral axis, but that, on the other side, from the low range of hills 6 miles west of

Srimangal to a distance of 30 miles from that place, a settlement of from 1½ to 9 inches has occurred. The author concludes that "there is little doubt that the earthquake was due to subsidence along the southern side of a normal fault cutting the rocks below the alluvium of the Sylhet district, and situated approximately under the major axis of the epicentral area". In Dr. Stuart the Geological Survey of India clearly possesses an officer who may be expected to deal adequately with the more interesting earthquakes which will probably occur before his term of service ends.

C. D.

Lead Ores. By T. C. F. Hall. Imperial Institute Monographs on Mineral Resources. 127 pp., with a map and two diagrams. London: John Murray, 1921. 6s. net.

THE genesis and mineralogy of the ores of lead is a subject of great interest and importance in itself, and it also forms part of a much larger question, namely, the existence of a definite generalized succession in depth of primary ore-zones. This is evidently of great economic importance as well as of much scientific interest, if it can be established, owing to its bearing on the problem of a possible change in the metal-content of ore-deposits when followed downwards. Evidence is rapidly accumulating that such a definite succession will in all probability eventually be established, and the facts so clearly stated by the author of this memoir will doubtless be of very great assistance in clearing up the question. It is here demonstrated that in a normal lead-zinc-silver deposit the silver-content is highest at the top, while in depth ore with dominant lead commonly gives place to zinc. Whether this in its turn should give place to copper, as is believed by many, still remains to be proved, though there is a considerable mass of evidence in favour of this idea.

This memoir follows the lines laid down in the preceding members of the series, and the author has made excellent use of the large amount of information available, preserving a due balance and bringing out the points of special interest. The information given is clear, up to date, and concisely expressed, while the views stated on the origin of lead ores, in many cases a subject of controversy, are fair and temperate, as might be expected from the author's wide practical experience. He is to be congratulated on having well performed a somewhat difficult task.

Geology of Mesopotamia and its Borderlands. Compiled by the Geographical Section of the Naval Intelligence Division, Naval Staff, Admiralty. 116 pp., with 5 maps and 9 figures. Stationery Office, n.d. Price, 5s.

THIS is, we believe, the first comprehensive summary of the geology of a little-known part of the world. In addition to the geology of Mesopotamia, the book contains much information

about Arabia, Armenia, Kurdistan, and Persia. The pioneers of Persian geology, Ainsworth (1838) and Loftus (1853), made long journeys in Mesopotamia and Persia. They give clear accounts of the formations and are remarkably correct in their determination of age and relation, but it was left to later travellers, of whom De Morgan is the best known, to work out the structure of this part of the world. From the works of these explorers and geologists this book has been compiled, and we suspect that the author, whose name is not given, has an intimate knowledge of at least part of this country.

The first seven chapters deal with the stratigraphy, structure, and geological history of the area; the latter part with the economic geology. A great part of Mesopotamia is covered with alluvial deposits of the Tigris and Euphrates. The underlying beds are for the most part of Miocene or Pliocene age. In Mesopotamia proper the oldest rocks exposed are Cretaceous, but in Kurdistan, Armenia, and Persia Jurassic, Permian, Carboniferous, Devonian, and Lower Palæozoic occur. Some granites and metamorphic rocks are referred to Archæan. Igneous rocks of Pliocene age also occur.

The most interesting and best known formation is the gypsiferous series, known in Persia as "Lower Fars". It crops out over a large part of Northern Mesopotamia and in South-West Persia chiefly in anticlines. In Armenia similar beds were described by Oswald. With regard to the age of these beds there is much difference of opinion, as Oswald correlates them with Tortonian, and Pilgrim in Southern Persia considers them Helvetian or Burdigalian. This is fully discussed pp. 77–83. Since this book was written, *Ostrea latimarginata*, which is looked upon as a zone fossil of the Burdigalian by the Indian palæontologists, has been found in the Lower Fars of Mesopotamia. This supports Pilgrim's views expressed in "The Geology of the Persian Gulf and adjoining portions of Persia and Arabia", *Mem. Geol. Surv. India*, vol. xxxiv, pt. iv, p. 31. Therefore we do not agree with the author when he states that Suess' suggestion that the gypsum beds (of Mesopotamia, Persia, etc.) represent the south-east extension of the Schlier (a special shallow water phase of the Burdigalian) cannot be maintained.

The structure of Mesopotamia is simple, and intimately connected with that of Persia. The important factor is a thrust from the north-east, which has caused rocks of all ages to be folded on an axis north-west–south-east. In Persia this thrust has caused tightly compressed and contorted folding, but in Mesopotamia the force seems to have spent itself with the result that more and more gentle folding is seen as one travels from east to west. The greatest period of folding took place in later Pliocene times, but we suspect that it had been going on along the same lines since Cretaceous times.

Chapter viii deals with economic geology. Plate viii gives all the recorded occurrences of minerals in the area covered by this book.

Mesopotamia is shown to be barren of minerals with the exception of petroleum. Coal is marked in several places, but an examination of the specimens from several of these localities indicates very strongly that the substance is an oil residue allied to "manjak". In Armenia a great variety of minerals occur, but inaccessibility would be a serious factor from a commercial point of view.

Chapter viii, part ii, the Persian-Mesopotamian Oilfields. This chapter will be read with great interest by oil technologists. As the oil is found for the most part in the gypsiferous series, the discussion of its age and origin is of great value.

The Geology of Mesopotamia and its Borderlands is concisely written, well illustrated with maps and sections, and provided with an excellent bibliography. In view of the prominence of Mesopotamia and Persia in the public eye, this publication is of great practical value.

A. H Noble.

The Mineral Industry of the British Empire and Foreign Countries. Imperial Mineral Resources Bureau Digests: Antimony, pp. 34, 1*s*. net; Cobalt, pp. 22, 9*d*. net; Aluminium and Bauxite, pp. 35, 9*d*. net; Zinc, pp. 112, 3*s*. 6*d*. net. Stationery Office, 1921.

THE general plan of this valuable series has been already described in a review of the first ten parts in the Geological Magazine for February of the present year. The four further publications listed above are drawn up on similar lines, the chief difference being in the much larger amount of space allotted to zinc, this, of course, being properly commensurate with its greater technical and industrial importance. Any such publications at the present time naturally form somewhat depressing reading, owing to the stagnation prevailing in almost all the mineral and metallurgical industries. Besides their value as a record of present resources and a forecast of future possibilities, they will always be most useful as a summary compiled from reliable sources of the general trend of the mineral industries during the war period. The extensive bibliographies in each section will be greatly appreciated by all workers on economic mineralogy.

The Radiolarian Cherts of the Franciscan Group. By E. F. Davis. Univ. Calif. Publ. Bull. Dept. Geol., vol. xi, No. 3, 1918. pp. 235–432, 16 text-figs., 14 plates.

THIS monograph on the Franciscan Cherts naturally divides itself into three parts: a descriptive and comparative study of the cherts of the Franciscan and the allied Monterey Group; a comparison with similar cherts in other regions, and finally a critical discussion of possible modes of origin.

There are two horizons of Franciscan chert, one 530 feet thick

and the other 900 feet. The cherts consist of iron-stained amorphous silica, in which are embedded the remains of radiolaria. These rarely form a large proportion of the chert. The amorphous silica is peculiar. It is hard enough to scratch quartz and contains much less water than opal. In the field these cherts are interbedded with thin siliceous shales, but the cherts make up by far the greater bulk of the rock. They appear to have a striking resemblance to the Culm Cherts of England, and differ both in mode of occurrence and petrographically from flint and many other occurrences of chert. The Franciscan Group has been invaded by basic intrusives, which have metamorphosed the cherts. In some cases the alteration results in a quartzite, but more peculiar changes are recorded such as the production of spherulitic and mammillated cherts, and occasionally, at the contact, of glaucophane schist.

Whilst the earlier and more descriptive parts of the paper are, perhaps necessarily, rather tedious, such a criticism does not apply to the concluding discussion of modes of origin. A comparison with radiolarian rocks of the West Indies shows that these cherts were not originally radiolarian oozes. Although the intercalation of these chert beds with sandstone indicates a shallow water origin, the author rejects the lagoon-phase theory of Dixon and Vaughan, largely because peculiar geological conditions are required of which there is no evidence, and because of the absence of calcareous remains. The enormous bulk of silica in these rocks is all out of proportion to the number of siliceous organisms present, and impossible to account for on the ground of precipitation from ordinary sea or river water. The general indications of igneous activity makes the author's supposition reasonable that submarine siliceous springs largely contributed the supply. It is further considered that this silica was precipitated together with terrigenous material, and that the rhythmic alternation was due to the segregation of the silica from the colloidal mass. The rhythmic bedding differs rather from the precipitation banding of Liesegang, on account of the continuous concentration of closely spaced bands, and also in the presence of transgressive bedding. This hypothesis is studied in a set of ingenious experiments on the rhythmic separation of a silica gel from intimate admixture with mud, and these deserve the close attention of all workers interested in segregation problems.

W. A. R.

The Foraminifera of the Bonaventure Cherts of Gaspé. By R. M. Bagg. *Bull. N. York State Mus.*, Nos. 219, 220. Fifteenth Report of the Director, 1918. 8vo., 60 pp., 6 plates. Albany, 1921.

THE careful examination of six thin rock sections of chert pebbles from the Bonaventure formation (Devono-Carboniferous) of the Gaspé Peninsula, Canada, by Dr. R. M. Bagg, has given

interesting results. These beds lie flat on vertical Devonian, Silurian, Ordovician, or Cambrian, and the included pebbles are recognizable fragments of the underlying rocks. Dr. Bagg considers the cherts to be Cambrian or Ordovician, and has identified seventeen genera and forty-five species of Foraminifera, many Sponges, some Radiolaria, Bryozoa, etc. The Foraminifera are uncrushed, present perfect outlines, and reveal many genera (as *Virgatina* and *Bolivina*) usually associated with more recent deposits. The paper is illustrated with four plates, and the carefully drawn figures of the sectioned specimens are placed side by side with the recent form. Altogether an important and interesting communication, involving a great deal of study and knowledge.

REPORTS AND PROCEEDINGS.

Liverpool Geological Society.

12th April, 1921.—W. T. Walker, Esq., B.Sc., F.G.S., President, in the Chair.

The following paper was read: "On certain Mineral Deposits in Stratified Rocks, with special reference to the Carboniferous and Trias." By H. W. Greenwood, F.G.S.

The mineral deposits dealt with included the lead and zinc deposits of the Carboniferous limestones of Somerset, North Wales, Derbyshire, Northumberland, and Cumberland, the copper deposits of Alderley Edge, Cheshire, and of Ecton, and the hematite deposits of North and South Wales, Lancashire, and Cumberland, all of which were considered to possess common characteristics summarized as follows, viz.:—

(1) The deposits are all younger than the rocks in which they occur, they all show definite signs of having been deposited at a period later than the major earth-movements of the areas in which they are found, and also later than the major denudation of the particular districts.

(2) Their component minerals have all reached their present position by a process of solution and percolation, and have obviously been derived from above and not from below, in which they are in marked contrast to magmatic ore bodies.

(3) They generally take the form of filling of joints, cracks, faults, solution fissures, and are often metasomatic replacements.

A detailed description of the various deposits was given, and evidence adduced to prove that the lead and zinc ores were certainly of post-Triassic age in the Mendip area, and of much later date in the other areas. In practically every area they occur at altitudes over 500 feet above sea-level, i.e. in areas of comparatively high relief. The hematite deposits on the contrary occur at relatively low levels,

and almost always at less than 500 feet above sea-level, and it was suggested that they had been derived from formerly overlying Triassic rocks. For the Trias as laid down, it was considered that a content of 2½ per cent of iron could not be regarded as an excessive estimate, which would be equivalent to 50,000 tons of hematite to a square mile of rock, 1 ft. thick, an amount quite adequate to account for the iron-ore deposits of the localities described.

Institution of Petroleum Technologists.

27th April, 1921.

"The Mackenzie Oilfield of Northern Canada." By Dr. T. O. Bosworth, F.G.S.

A great expanse of Devonian rocks is exposed in the Mackenzie basin of the North-West Territory. It extends northward beyond the present railroads of Northern Alberta for more than a thousand miles to the Arctic coast. Since the exploration of the region by R. G. McConnel in 1887, who mapped the general boundary of the Devonian area, no further geological study was made until 1914. In that year Dr. Bosworth led a geological expedition to investigate the stratigraphy and structure of the Devonian rocks and to search for oil. Several prospective oilfields were outlined by this expedition, and sites for test wells were selected. At length, in 1919, drilling machinery was sent into the north, and in 1920 the No. 1 test well was drilled, with the result that oil in large quantity has been struck at a depth of 783 feet. This discovery well is the first well drilled in the North-West Territory. It is within 90 miles of the Arctic Circle and is the most northern oilwell in the world.

The author has divided the Devonian of this region into the following members :—

Camp Creek Series.
  Clay shales and green oilsands, thickness 2,000 feet.
Fort Creek Shales.
  Bituminous black shales, thickness 500–1,000 feet.
Beavertail Limestone.
  Bituminous dark limestones, thickness 350 feet.
Rampart Limestone.
  Massive fossiliferous grey limestone, thickness 100–200 feet.
Hare River Shales.
  Calcareous clay shale, thickness 300 feet.
Barren Series.
  Brecciated dolomites and massive grey limestone, probably only in part Devonian, thickness 2,000 feet.

The Devonian strata in the Mackenzie Oilfield have been thrown into a series of bold asymmetrical folds. Four main anticlines were determined, parallel to one another, and about 7 miles apart. Their direction, where the river crosses them (80 miles beyond Fort Norman), is slightly north of east ; but on the east side of the